UNIVERSIDAD COMPLUTENSE DE MADRID

FACULTAD DE CIENCIAS GEOLÓGICAS

Departamento de Paleontología

TESIS DOCTORAL

Paleobiogeografía, cambios climáticos globales y macroevolución en aves no paseriformes: patrones de radiación, dispersión y adaptación durante el Cenozoico

MEMORIA PARA OPTAR AL GRADO DE DOCTOR

PRESENTADA POR

Jonathan S. Pelegrin Ramírez

Directores

Manuel Hernández Fernández
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PALEOBIOGEOGRAFÍA, CAMBIOS CLIMÁTICOS GLOBALES Y MACROEVOLUCIÓN EN AVES NO PASERIFORMES:

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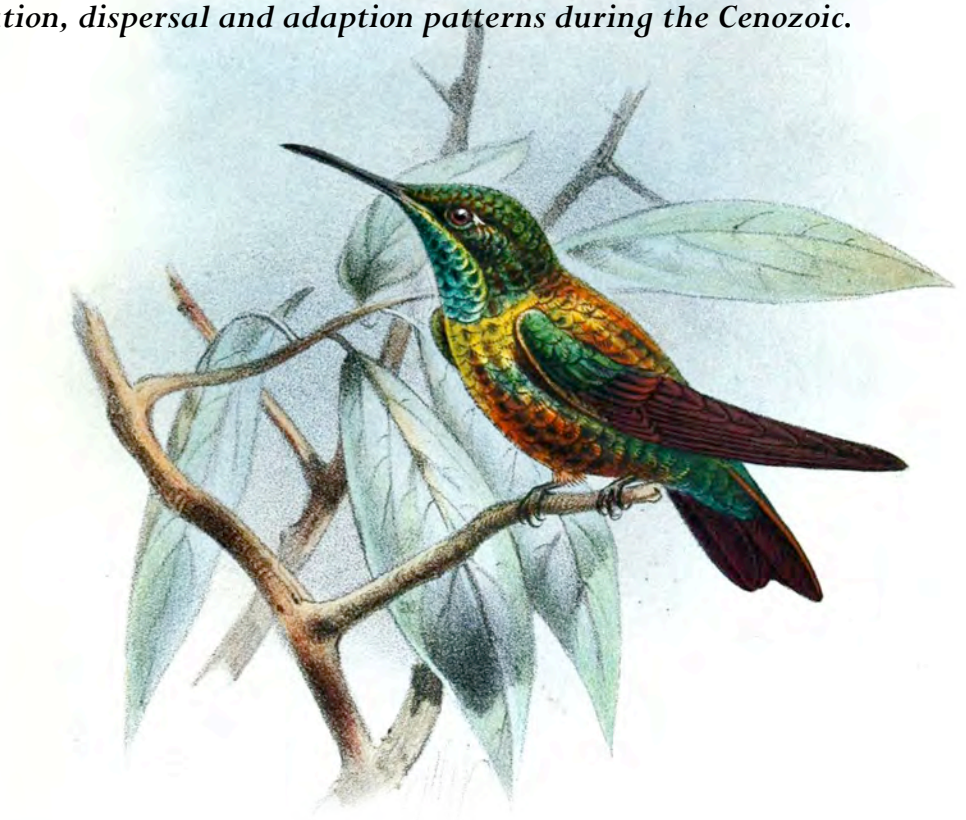

JONATHAN S. PELEGRIN RAMÍREZ

TESIS DOCTORAL

Ph.D. Thesis

Directores:
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CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS
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UNIVERSIDAD COMPLUTENSE DE MADRID

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Memoria de Tesis Doctoral presentada por

JONATHAN S. PELEGRIN RAMÍREZ

Bajo la supervisión de los doctores:

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Manuel Hernández Fernández	Juan López Cantalapiedra	Jonathan S. Pelegrin Ramírez

Charles Darwin (1836)

A Tita…

Species evolve exactly as if they were adapting as best they could to a changing world, and not at all as if they were moving toward a set goal.

George Gaylord Simpson (1902-1984)

Science is more than a body of knowledge. It's a way of thinking, a way of skeptically interrogating the universe.

Carl Sagan (1934-1996)

The Homo sapiens also ranks as a "thing so small" in a vast universe, a wildly improbable evolutionary event, and not the nub of universal purpose. Make of such a conslusion what you will. Some people find the prospect depressing. I have regarded such a view of life as exhilarating- a source of both freedom and consequent moral responsibility. We are the offspring of history, and must stablish our own paths in this diverse and interesting of conceivable universes-one indifferent to our suffering and therefore offering us maximal freedom to thrive or to fail, in our own chosen

Stephen Jay Gould *Rock of Ages* (1999)

Esta tesis doctoral ha sido financiada gracias a una beca predoctoral Francisco José de Caldas de Colciencias (Colombia) y por el proyecto CGL2010-19116/BOS del Ministerio de Ciencia e Innovación (España). Este trabajo ha sido realizado dentro del grupo de investigación UCM-910607 "Evolución de mamíferos y paleoambientes continentales cenozoicos" y el equipo de investigación "Paleoclimatología, Macroecología y Macroevolución de Vertebrados (PMMV)".

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Es indudable que esta Tesis Doctoral representa el esfuerzo de muchos años, el empeño no sólo del autor, sino de todas aquellas personas que de una u otra manera aportaron ideas, comentarios, revisiones y sugerencias. No puedo decir que esta tesis es solo mía, su consolidación no habría sido posible sin la constante guía y apoyo de mis directores. Dos personas que mitifican lo que es un linaje académico, el Dr. Manuel Hernández Fernández y el Dr. Juan López Cantalapiedra. A ambos quiero agradecer profundamente vuestra confianza, el aliento en las dificultades, no os lográis imaginar cuanto he aprendido de vosotros. Gracias no sólo por tutelar esta tesis, gracias por la calidad humana brindada, por la amistad, por las charlas y consejos no sólo de evolución y paleontología, sino de la vida misma, de series, política, música, y un largo etc. Sólo puedo decir que para mi ha sido un honor trabajar al lado de personas como vosotros.

Pero conocer a Manuel y a Juan fue gracias a una cantidad de acontecimientos. Creo personalmente que las cosas se comprenden de una mejor manera a la luz de la historia, y en la vida de una persona hay diversos momentos clave para la misma. Esta tesis posiblemente es el resultado de muchos acontecimientos, de muchas personas, así que espero no dejarme a nadie en el tintero y si es así disculpad a mi cabeza…

En un caluroso Agosto de 2001, un joven bachiller hacía una larga fila para reclamar los documentos de admisión al programa de biología de la Universidad del Valle. Durante mis años previos había estudiado en un colegio rodeado de naturaleza, y con muchos animales disecados que llevaban décadas en estanterías de los laboratorios, fue probablemente gracias a las clases de mis profesores de ciencias que un simple amante de los animales, al que le gustaba dibujarlos, terminase contingentemente escribiendo estas líneas, realmente fue allí dónde me enamore de la ciencia. A lo largo de los primeros años en la facultad veía clases con profesores que me inspiraban mucha admiración, esto hacía que a veces me preguntase: ¿hasta dónde llegaré? ¿seré algún día un gran científico?… La Universidad sin duda alguna constituyó un importante fermento intelectual, no sólo para mi crecimiento académico en las ciencias biológicas, sino que me ayudó a ser más consciente y crítico de la sociedad en que vivimos, de

alguna manera fue salir de una burbuja. Por eso debo agradecer a la Universidad del Valle, mi formación académica, y seguramente la base conceptual de esta Tesis Doctoral.

Ya son casi 15 años desde que comencé mi andar por la biología y cada día que pasa siento que no pude tomar una decisión más acertada en mi vida. Durante mis cursos de Zoología de Vertebrados y Teoría evolutiva me di cuenta que la evolución animal era lo que quería estudiar y sería leyendo los libros de Stephen Jay Gould cuando alcanzaría a dimensionar los grandes aportes que ha hecho el estudio de los fósiles a nuestra comprensión del proceso evolutivo. Mi formación como Biólogo Zoólogo en Univalle no habría sido la misma sin mis profesores y profesoras de la facul. Algunos me marcaron profundamente por su alta calidad científica y humana. El Dr. Philip Silverstone, creo que no he conocido a alguien tan humilde y a la vez tan sabio. Al Profesor Humberto Álvarez-López, no sé si algún día llegaré a saber tanto de "pájaros" como él. Igualmente, a los Profesores Manuel Giraldo, Fernando Quintero, Patricia Chacón, Fernando Castro, Harold Hollaender, Nancy Carrejo, Wilmar Bolivar, Santiago Castaño, Luis María Borrero, entre muchos otros que aportaron en la construcción de mi pensamiento científico y me llevaron a convertir la ciencia en mi forma de ver el mundo.

Los anteriores fueron eventos y personas importantes y necesarios para que yo logrará consolidar esta Tesis Doctoral. Sin embargo, aún falta uno muy importante y determinante… Después de terminar mi carrera como Biólogo, decidí que quería continuar aprendiendo y profundizando el estudio de la evolución y la paleontología. Esto me llevó a aventurarme y decidir partir de mi Universidad, ahora era otra burbuja de la que había que salir. El primer paso que di en esa dirección fue gracias a una estancia de investigación en el Smithsonian Tropical Research Institute de Panamá, donde tuve el privilegio de conocer e introducirme inicialmente en el mundo de la paleontología en el equipo del Dr. Carlos Jaramillo, donde conocí gente valiosa como el Dr. Edwin Cadena. A ambos agradezco infinitamente todo lo aprendido.

Sin embargo, tras un tiempo en STRI consideré necesario continuar con mi formación académica, quería conocer una nueva escuela, experimentar otras formas de investigar y pensar, y así decido ir a Europa. El llegar a España fue algo muy especial para mi, era iniciar otra fase, era un reto personal. Tras ingresar al Master en Biología Evolutiva de la UCM, conocería gente maravillosa que aportó a la construcción de nuevos procesos y conceptos. Quiero agradecer a los profesores y profesoras del Master, en especial a Pepe Díaz, Francisco Pulido, Fernando Pardos, Manuel

Hernández Fernández y Patricio Domínguez Alonso. Ambos serían muy importantes para mi, el primero por tutelar mi trabajo de fin de Master y confiar en este "advenedizo" (gracias de nuevo Manuel) y el segundo porque sería alguien con quien compartiría mi segunda pasión científica, la astronomía, aún recuerdo su charla sobre Geología Lunar. Patricio, vivirás por siempre en las mentes de quienes te recordamos. Poco a poco y con el pasar de los meses, la Universidad Complutense de Madrid se había consolidado como mi segunda casa académica. Creo que debo agradecer a la Universidad en general, paradójicamente como toda universidad pública me recuerda mucho a mi amada Univalle en muchos de sus rincones, tienen un potencial humano enorme, mucha gente que ha luchado por una academia de todas y todos. La Complu me acogió y la verdad, debo confesar, que la echaré de menos el día que ya no camine por sus pasillos.

Con el inicio de mi proceso doctoral, y tras una larga lucha de becas y trámites (aquí y allá), debo agradecer a Colciencias su apoyo económico sería fundamental para la realización de este proyecto. Gracias a su respaldo podría llegar al Departamento de Paleontología y al Instituto de Geociencias que se convertirían prácticamente en mi casa durante estos años de investigación. Aquí fui muy bien recibido, y me integraría a un personal docente, investigador y de servicios de una alta calidad humana. Gracias a todos y todas en general por los momentos compartidos durante estos años, en el día a día de los pasillos, personas como las profesoras Graciela Sarmiento y María Teresa Fernández o Doña Charo Palomo con su amabilidad hicieron más grata mi estancia. Quiero agradecer en especial al entusiasmo y disposición de la Profesora Marián Álvarez Sierra, quien me integró a su grupo de investigación. Una mujer apasionada por la paleontología, y que posee unas cualidades académicas y personales excepcionales. Marián es una digna representante del linaje de Nieves López, a quien desafortunadamente no conocí, pero que sin duda sigue más viva que nuca dentro de las enseñanzas de sus hijos académicos.

La importante relación entre los departamentos de Paleontología de la UCM y Paleobiología del MNCN permitiría mi integración a una gran familia, a la que cariñosamente llamo "*la Paleopeople*", quienes además de compartir muchas inquietudes académicas, comparten la concepción crítica de una sociedad más justa, que valore la ciencia como motor fundamental. Pero también es un grupo que ve muchas series y películas, viaja un montón y va a muchos festivales. Habéis constituido mi circulo social estos años, gracias totales por vuestra amistad y compañerismo. Paloma, Blanca, Ana, Laura y Sole, Juan, Óscar, Xabi, Javi, Alberto, Omid, María, Adri, Gema, Vero,

Miriam, Laura B, Enrique, Isra, Mario, Paco… Personas que he conocido a través de este maravilloso mundo que es *la Paleo*, gente apasionada, gente que lo vive… a muchos doctorandos que aún quedan y a quienes les he tomado un gran cariño Sara, Marco, Fercho, Iris, Dani H, Roselis… sólo os digo, gracias por vuestra amistad, os deseo lo mejor y ánimo!… a mis compañeros de despacho Ricardo, Omar, Patri e Ismael gracias por las charlas y ayudarme en muchas ocasiones a salir de la monotonía.

Asimismo, quiero agradecer al profesor Jorge Morales la oportunidad de compartir de sus valiosos conocimientos y amplia experiencia durante las campañas de excavación. Seguramente muchas generaciones de paleontólogos son y serán inspirados por la figura de un hombre como Jorge. En general agradezco a la vida los momentos compartidos con todas las personas, tanto estudiantes como investigadores en las campañas, en los EJIPS, en los diversos congresos, hay una retroalimentación constante que te ayuda a crecer.

Estos agradecimientos son especiales, me saben también un poco a despedida, no lo puedo evitar… Aunque planeo volver, esta etapa de posgrado en España ha sido bastante fructífera, no sólo en el ámbito académico, también en el personal. Me llevo el recuerdo de amistades muy valiosas, mis amigos fuera de la facultad "*los brothers*", que me han hecho sentirme aún más en casa, mis compañeros de piso que han reemplazado un poco a mi familia y en general, a muchas personas maravillosas que he conocido en Madrid, son muchos los buenos recuerdos. Finalmente y no menos importante, todo lo contrario, estar aquí también me llevó a conocer a alguien muy especial, un apoyo fundamental durante parte del desarrollo de esta Tesis… Gracias Bea!.. vos pese a ser ingeniera siempre dispuesta a escuchar los ensayos de mis charlas precongreso de "pajaritos monos", gracias por llevarme a ver avutardas (*Otis tarda*, por no perder el rigor, jejeje), por estar ahí, por los viajes, por llegar a mi vida, por aceptarme y quererme tal como soy, no tengo palabras para expresar lo importante que te has vuelto para mi, pase lo que pase estarás por siempre en mis recuerdos.

A lo largo de estos años mi corazón siempre ha estado dividido, son muchos los años fuera de Colombia y estos también me han servido para reafirmar la importancia de muchas personas en mi vida. Muchas de ellas a pesar de los casi 10.000 km han seguido ahí. Gracias a mis amigos, sin vosotros tampoco hubiese sido posible esta tesis, debo confesar que hay días en que extraño y recuerdo con nostalgia muchos de nuestros momentos. A mis amigos y amigas de la carrera "*el parche de biólogos*" Jaco, Pablo, Nacho, Frank, Fabián, Diego y Daniel. También gracias a Diana, Ana y Alba que al igual que yo decidieron emprender esta aventura de hacer un postgrado fuera de

nuestra tierra. Fuisteis fundamentales en muchos momentos cuando echas de menos el verano eterno de Cali o cuando nos agobiamos con nuestras tesis… ¿qué te parece lo que he escrito? También debo agradecer a mis amigos y compañeros de la Escuela de Astronomía de Cali su visión de divulgar la ciencia y llevarla a todos me enamoró de este grupo. He echado de menos los cursos, las charlas, las salidas de observación, las risas (Marino, Yolanda, Ariel, Carlina, Juan Carlos). Alejo, el presidente de la EAC, futuro doctor en química orgánica y uno de mis mejores amigos, sólo puedo agradecerte por estar ahí en muchas dificultades y miedos. Gracias por las horas de Skype y llamadas, por hacerme sentir más cercano. No imaginas como he echado de menos nuestras charlas de ciencia, política, educación y vivencias propias.

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No puedo acabar sin dar gracias a todos y cada uno de los estudiantes que hasta ahora he tenido, desde los colegios hasta las universidades, he aprendido muchísimo de todos ellos y ellas, algunos incluso se convirtieron en grandes amigos (sí Mapa, ¡es por vos!). Muchos me han dado inmensas alegrías, verlos avanzar y crecer, incluso ser científicos, ese es el mayor premio. Generar y transmitir el conocimiento es algo maravilloso y es algo que espero pueda seguir haciendo hasta que me falte el aliento.

A lo largo de todos estos años, de toda esta historia personal, ha estado mi familia. No por nombrarlos al final son menos importantes, todo lo contrario, son aquellas personas constantes en tu vida, aquellas que seguramente te acompañaran hasta el final de tus días. Esta tesis también es producto de ellos, el apoyo de mis padres para estudiar siempre fue fundamental. Quiero agradecer especialmente a mi Madre y a "Tita", donde quiera que estés. Mi vida no sería nada sin vosotras, soy lo que soy gracias a vuestras luchas y sacrificios, al amor que siempre recibí de mi abuela Tita, a su cariño por la naturaleza, aún recuerdo como se alegraba con el canto del bichofué (*Pitangus sulfuratus*) en las mañanas o como cuidaba las ranas de mi tesina de licenciatura. Gracias a mis hermanas por su cariño y comprensión, a veces puedo ser insufrible dando

consejos. En general, gracias a toda mi familia aquí en España, habéis hecho menos solitaria mi estancia y un poco más alegres las navidades.

Finalmente quiero pedir disculpas a todas aquellas personas que me pude dejar en el tintero… supongo que en ocasiones somos victimas del tiempo y el espacio, factores que a la final construyen la historia de quien somos, la distancia y el tiempo a veces hacen que el olvido sea inevitable, así que sólo puedo decir a los ausentes…

…Es muchísima la gente a la que conoces, la que en el largo transcurrir de los días te aporta un granito de arena en quien eres… si alguno de ellos faltase en la larga cadena de la vida, simplemente esta no sería igual…

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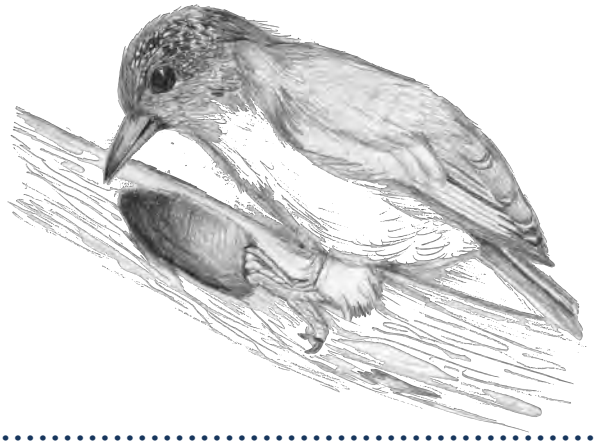

Las imágenes e ilustraciones empleadas para la ambientación de esta memoria de tesis doctoral son creaciones originales del autor de la misma y de diversos artistas e ilustradores a quienes quiero agradecer su importante labor, esta tesis es también un homenaje a ustedes:

A…John Gould (1804-1881)
A…John Gerrard Keulemans (1842-1912)
Al algunos de los ilustradores del Handbook of the Birds of the World: R. Allen, N. Arlott, H. Burns, C. Byers, M. Elliott, A. Gilbert, M. Hulme, A.Jutglar, F. Jutglar, I. Lewington, A. Lombarte, D. Pratt. C. Rose, L. Sanz, L. Solé, E. Vilaró, J. Wilczur, I. Willis, T. Worfolk.
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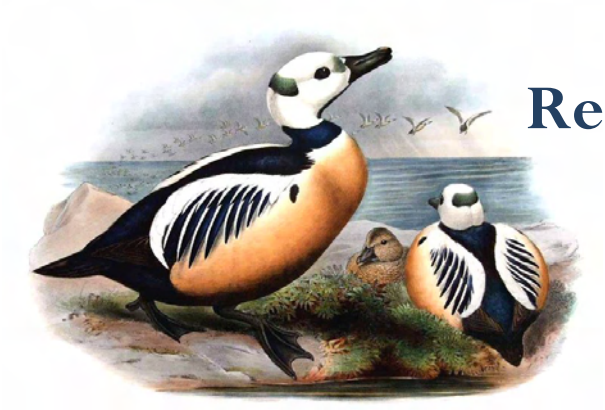
Breve prefacio

Con cerca a 10.000 especies en la actualidad, las aves representan uno de los grandes hitos en la evolución de los vertebrados. Su historia comenzó hace 150 Millones de años. Sin embargo, fue realmente a finales del Cretácico cuando llegó la oportunidad histórica que permitiría a las aves modernas evolucionar hasta el grupo que son hoy día y demostrarnos así que los dinosaurios siguen tan vivos como antaño. El destacado éxito evolutivo que alcanzaron se debe fundamentalmente a muchas adaptaciones desarrolladas a partir de una amplia diversidad de morfologías, dietas y una prominente capacidad voladora. El destacado desarrollo de estas características habría desempeñado un importante papel en el proceso de colonización de diferentes continentes y sus biomas en diversos periodos a lo largo del Cenozoico, alcanzando en la actualidad una amplia presencia en todos los ecosistemas de la tierra: desde las selvas lluviosas en los trópicos hasta las tundras árticas, lugares en donde son un componente esencial de las comunidades y sus entramados tróficos. Teniendo en cuenta la importancia del estudio de la avifauna como un elemento clave de la biodiversidad, esta Tesis Doctoral, integrando un marco neontológico y paleontológico, pretende reconstruir, empleando diversas metodologías, este recorrido por la historia evolutiva de las aves para conocer cómo los diferentes procesos de cambios físicos globales han influido en su evolución, configurando de esta manera la diversidad que vemos en nuestros días.

Resumen - Abstract



Resumen

PALEOBIOGEOGRAFÍA, CAMBIOS CLIMÁTICOS GLOBALES Y MACROEVOLUCIÓN EN AVES NO PASERIFORMES: PATRONES DE RADIACIÓN, DISPERSIÓN Y ADAPTACIÓN DURANTE EL CENOZOICO

Introducción

Desde su origen en el Jurásico, las aves adquieren una preponderancia en los ecosistemas alcanzando cerca de 10000 especies en la actualidad, una diversidad sin parangón entre los vertebrados terrestres. Desde los comienzos de las ciencias naturales, las aves fueron uno de los grupos animales más estudiados, lo que las ha llevado a ser sin duda uno de los mejor conocidos en términos de su ecología y distribución geográfica. En los últimos años, esta vasta acumulación de conocimiento ha posibilitado el surgimiento de nuevos análisis para conocer sus patrones de diversidad y las causas subyacentes a los mismos. Sin embargo, a pesar de la abundancia de trabajos relacionados con diversos aspectos de su biología y el creciente auge de la aplicación de técnicas moleculares, son pocos los trabajos que integren las diversas fuentes de información en una perspectiva macroevolutiva. Asimismo, muchos trabajos suelen considerar el registro fósil de las aves como deficiente o poco representativo, siendo también escasos los estudios paleoecológicos con implicaciones sobre la evolución de este grupo.

Considerando lo anterior, esta tesis doctoral se plantea como objetivo fundamental determinar cómo los diversos patrones y procesos macroevolutivos de las aves modernas (Neornithes) han sido influidos por los cambios climáticos y procesos geológicos que han acaecido en la Tierra a lo largo del Cenozoico. Por lo tanto, el presente proyecto de tesis se constituye como un reto importante en la integración de toda la información disponible para construir un marco histórico que logre explicar procesos evolutivos de innovación adaptativa responsables de la importante disparidad ecológica que observamos actualmente en las aves. La disparidad morfológica que presentan los diversos clados ha sido producto de la adaptación a diversos regímenes

dietarios y por ende esta tiene un vinculo directo con los procesos macroecológicos y macroevolutivos del ambiente donde se desarrollaron.

Los análisis de los diversos procesos ecológicos y evolutivos que han configurado la diversidad que observamos en las aves fueron abordados desde una visión filogenética y abarcando una escala taxonómica desde el nivel de especie, hasta el de familias y órdenes. Las diversas escalas de estudio nos permitieron utilizar aproximaciones nuevas e inferencias macroevolutivas en un contexto espacio-temporal amplio y a la vez detallado. Lo anterior fue posible gracias a la conjunción de metodologías clásicas que serían probadas por primera vez para aves, así como la aplicación de nuevos métodos de análisis que integran las relaciones filogenéticas, la historia paleoclimática y paleoecológica, y el registro fósil en un marco paleobiogeográfico.

Síntesis

La hipótesis del uso de los recursos propuesta por E.S. Vrba establece un escenario macroevolutivo que conecta ecología (grado de especialización en la ocupación de biomas), cambios físicos ambientales a gran escala y eventos de especiación y extinción. Esta hipótesis, originalmente constituida a partir de estudios con faunas de mamíferos del Neógeno-Cuaternario africano, propuso un sólido marco explicativo de sus procesos evolutivos. En el capítulo 2 de esta tesis doctoral se evalúa por primera vez la validez de esta hipótesis a partir de los datos derivados de todas las especies actuales de aves no paseriformes (N = 3951). Para esto, nuestros análisis se basaron en comparar los patrones de distribución observados para las ocupación de los biomas por parte de distintas especies con un escenario donde la ocupación de los biomas sigue un patrón aleatorio y por lo tanto, la especialización ecológica en biomas no influye en dicha distribución (modelo nulo).

Los resultados alcanzados son consistentes con lo propuesto por la hipótesis del uso de los recursos, la cual fue analizada sobre sus tres premisas fundamentales. La primera propone que a causa de sus mayores tasas de especiación y extinción, existirá una mayor proporción de especies especialistas de bioma que de generalistas. Por su parte, la segunda premisa establece que debido a sus características ecológicas, ciertos clados tenderán a ser más especialistas con respecto a otros. Este aspecto fue ampliamente respaldado por nuestros hallazgos, en estos, los clados faunívoros presentaron una tendencia a ser más generalistas que los herbívoros, con los omnívoros

en una posición intermedia. De igual modo, la migración mostró ser una importante estrategia adaptativa que favoreció la ocupación y diversificación de diversos linajes en ambientes hostiles y en contra de los supuestos iniciales no afectó las tendencias generales. Finalmente, la tercera premisa establece que existirá una prevalencia de especies especialistas en la pluvisilva, el desierto, la estepa y la tundra, biomas que representan extremos del gradiente climático terrestre y son altamente susceptibles a los procesos de reducción-fragmentación y expansión durante los periodos de cambio climático. Por tanto, dichos biomas constituyen importantes escenarios de especiación y extinción. Aunque no se contemplaban dentro de las premisas de la hipótesis, también se obtuvieron importantes evidencias de la influencia de los gradientes altitudinales en los trópicos, la heterogeneidad de hábitat y los eventos faunísticos del Neógeno en los patrones macroevolutivos de las aves.

En el capítulo 3 se realizó un análisis que consideró las relaciones filogenéticas de todas las aves actuales y sus parientes fósiles mejor conocidos. Este sería el punto de partida que permitió establecer diversos escenarios paleobiogeograficos (modelos) teniendo en cuenta los cambios tectónicos y climáticos que ha sufrido la Tierra a lo largo de la evolución de las aves actuales. Debido a que sin duda el vuelo y sus diversas variaciones han sido claves en el éxito evolutivo que de las aves, los diversos escenarios paleobiogeográficos fueron analizados de acuerdo con diferentes capacidades de dispersión que tienen en cuenta la historia particular de cada uno de los grandes clados de Neornithes. De acuerdo con lo anterior, se estableció estadísticamente el escenario biogeográfico más probable para cada clado y para todas las aves no paseriformes a través de una nueva metodología que permitió integrar gran cantidad de información paleogeográfica, paleoclimática, fósil y reciente.

De acuerdo con los resultados obtenidos, la evolución inicial de las primeras Neornithes estaría asociada a Sudamérica. Los modelos con mayor probabilidad sugieren que este continente habría jugado un papel clave como refugio durante los periodos de importante cambio ambiental que sucedieron durante el Cretácico Superior y que ocasionaron la extinción de otros linajes de vertebrados. De esta manera, a lo largo de la historia evolutiva de las Neornithes, diversos eventos de dispersión y colonización habrían sido fundamentales para posteriores procesos de vicarianza y diversificación dentro de diferentes linajes. El primer evento destacado habría sucedido durante el Cretácico superior donde los ancestros de importantes

linajes cursoriales y acuáticos como Paleognathae, Galloanseres y Aequornithes se dispersan desde Sudamérica hacía África, la Antártida y Norteamérica. Asimismo, según nuestros resultados, una segunda ola de diversificación se habría producido a finales del Paleoceno y comienzos del Eoceno. Este evento habría sido protagonizado principalmente por linajes de aves arborícolas y con destacada capacidad voladora, como diversas familias dentro de Caprimulgiformes y Afroaves. Los patrones observados sugieren una posible relación entre estos procesos y la expansión de los ecosistemas tropicales hacia altas latitudes durante este periodo. Posteriormente, durante el Oligoceno importantes cambios globales, con la aparición de nuevas configuraciones oceanográficas y biomas abiertos debido a las tendencias de enfriamiento global, serían factores condicionantes en la transformación de muchos ecosistemas. Según lo anterior, nuestros resultados sugieren que la creación de nuevos nichos generó un destacado pulso de dispersión en linajes marinos y terrestres. Durante este periodo, muchas aves playeras y marinas (Charadriiformes y Procellariiformes), así como los linajes modernos de Galliformes, Otidiformes, entre otros adaptados a ambientes abiertos, presentarían una prominente diversificación. Finalmente, durante el Mioceno superior y el Plioceno, con la intensificación del régimen estacional en el Hemisferio Norte, importantes eventos de contracción y retracción de los bosques tropicales hacia latitudes ecuatoriales causarían la extinción de diversas familias en los emergentes ambientes templados estacionales y las confinarían a sus distribuciones pantropicales actuales.

En el capítulo 4 se explora cómo se han configurado los patrones de ocupación de los diversos biomas desde una perspectiva filogenética. Esto permitió integrar la conservación del nicho al contexto explicativo de la dinámica biómica. Como quedaría patente en el capítulo 2, los biomas se consolidan como unidades ecológicas claves para estudios macroevolutivos y macroecológicos, debido a que su estructura e historia están estrechamente ligadas a cambios climáticos y geológicos. Igualmente, la señal filogenética implícita en la evolución de los taxones ofrece la posibilidad de estudiar a través de nuevas técnicas de análisis los patrones históricos de la ocupación y diversificación de las aves en estas "arenas evolutivas".

Galliformes y Falconiformes son dos grupos con una marcada y amplia presencia en los ecosistemas terrestres. Del mismo modo, estos grupos han desarrollado unas adaptaciones ligadas a dos estrategias tróficas diferentes como herbívoros y faunívoros

respectivamente. El amplio conocimiento de sus relaciones filogenéticas a nivel de especie y su información ecológica permitió abordar el estudio de su dinámica histórica en la ocupación de biomas. Esto posibilitó la obtención de modelos macroevolutivos para conocer qué factores y cambios ambientales fueron fundamentales en la ocupación de los diferentes biomas, y si existen tendencias comunes en los grupos a pesar de sus diferencias ecológicas. Estas aproximaciones también hicieron posible arrojar mayor luz sobre cuáles son las principales tendencias en la evolución del nicho climático respecto a la ocupación de ciertos ambientes mediante la evaluación del concepto de conservacionismo filogenético de bioma.

Los resultados del capítulo 4 muestran una amplia consistencia con el principio de la conservación de nicho para ambos grupos, siendo estadísticamente preponderante en la mayoría de los biomas, y especialmente marcado en los biomas extremos dentro del gradiente climático. Estos hallazgos reflejan el importante desarrollo de unos ajustes fisiológicos y morfológicos para la invasión de ciertos biomas, muchas de estas a su vez tendieron a posibilitar posteriores colonizaciones, como es el caso de las adaptaciones a climas fríos. Igualmente, los diversos cambios climáticos acaecidos durante el Mioceno habrían sido fundamentales en los patrones de diversificación de ambos grupos. Durante este periodo, la adaptación y amplia ocupación de biomas secos y estacionales como el bosque seco tropical y la sabana, habría permitido la posterior colonización de otros biomas, tanto tropicales como templados. Finalmente, para ambos grupos el bosque seco tropical resulta desempeñar un rol clave para sus procesos de diversificación.

Conclusiones

En general, nuestros resultados ofrecen una visión holística del importante papel que han desempeñado los cambios climáticos globales y los procesos tectónicos en la configuración de la diversidad y disparidad moderna de las aves no paseriformes. Nuestra aproximación evidencia cómo a través del estudio de las faunas actuales y sus relaciones filogenéticas pueden obtenerse inferencias macroevolutivas de gran poder explicativo. Finalmente, este estudio abre una nueva perspectiva que integra información neontológica y paleontológica en un contexto histórico para entender y arrojar mayor luz a la compleja evolución de las aves modernas desde su origen a nuestros días.

Abstract

PALEOBIOGEOGRAPHY, GLOBAL CLIMATE CHANGES AND MACROEVOLUTION IN NON-PASSERINE BIRDS: RADIATION, DISPERSAL AND ADAPTION PATTERNS DURING THE CENOZOIC

Introduction

Since their origin in the Jurassic period, birds have acquire an important role in Earth ecosystems with an outstanding diversity of near 10,000 species among modern terrestrial vertebrates. During the early history of natural sciences, birds were one of the most studied biological groups. As a result, birds are one of the best-known animal groups in terms of their ecology and geographic distribution. This vast accumulation of knowledge has enabled the emergence of new analyses to understand their diversity patterns and their underlying triggering factors. However, despite the relative abundance of studies about diverse aspects of their biology and the growing availability of molecular phylogenetic trees, we still lack comprehensive perspectives on some key aspects of their macroevolution. Also, many studies usually consider the bird fossil record as deficient or under-representative; due to this, there are few studies about paleoecology and evolutionary implications in this group.

In this context, this thesis has the aim of determining the influence of past climate changes and geologic processes in the macroevolutionary patterns of modern birds lineages (Neornithes) along the Cenozoic. In addition, this thesis project represents itself a challenge in the integration of all available information to generate a historical framework and explain evolutionary key innovations that allowed the ecological disparity that we observe in living birds. The broad morphological disparities among bird clades are the product of adaptation to different dietary regimes.

Undoubtedly, this morphological diversity has a link with ecological and evolutionary processes in the environments where bird lineages developed.

The study of the evolutionary processes that rendered the diversity of living birds was addressed under a phylogenetic perspective considering a broad taxonomic scale: from species level to families and orders. The diverse study scales allow us to employ new approaches and macroevolutionary inferences in a broadly spatial and temporal scope, but also with a significant detail level. In short, we integrated classic and new methodologies, which were tested for first time in birds in a macroevolutionary context, and combined phylogenetic information, paleoclimatic and paleoecological history, as well as vast information from the fossil record in an integrative paleobiogeographical frame.

Synthesis

The resource-use hypothesis proposed by E.S. Vrba establishes a connection between ecology (specialization in the occupation of biomes), large-scale physical changes of the environment (climate, tectonics, etc.) and speciation and extinction events. This hypothesis, originally formulated for African Neogene-Quaternary mammalian faunas, proposed a robust framework to explain the evolutionary processes. In Chapter 2 of this dissertation, the validity of this hypothesis is evaluated here for all the species of non-passerine birds (N = 3951) for the first time. In particular, we compared the observed distribution patterns of the different species in the current biomes respect to a null scenario generated randomly.

The results obtained are consistent with the three fundamental premises of the resource-use hypothesis. The first one suggests that due to their higher rates of speciation and extinction, the clades will present an overrepresentation of biome specialists (i.e. species restricted into a single biome) in relation to the proportion of generalists. The second premise states that due to its ecological features, certain clades will tend to be more specialist than others. This point was broadly consistent with our findings. Faunivorous clades were more generalist than herbivorous clades. Omnivores showed an intermediate position. Likewise, migratory behaviour showed to be an important adaptive strategy that allowed the occupation and diversification of many lineages in hostile environments and, against initial assumptions, did not affect overall

trends of biome specialization. Finally, the third premise establishes that there will be a prevalence of specialist species in the tropical rainforest, desert, steppe and tundra biomes. These environments are extremes of the climate gradient are highly susceptible to the fragmentation and reduction-expansion processes during climate change periods. Therefore, these biomes constitute important scenarios of speciation and extinction in bird lineages. Although not contemplated within the hypothesis premises, we obtained important evidences of influence of biome specialization due to altitudinal gradients in the tropic highlands, heterogeneity of habitat and biotic interchanges events during the Neogene on the macroevolution patterns of non-passerine birds.

According with the chapter 3, based in the phylogenetic relationships of all living birds and their best-known fossil relatives, we assessed different biogeographic scenarios for the evolution of birds. The implemented analysis considers all palaeogeographic evidence of tectonic and climatic changes on Earth along the evolution of modern birds. In this context, the flight and its different variations have been key to evolutionary success of birds. Respect to this, we established statistically the most probable biogeographic scenario for all bird high-clades and for Neornithes using maximum likelihood criteria. Our methodology allowed us integrating geographic, historical fossil and recent information.

Our findings suggest that early evolution of the first Neornithes took place in South America. This continent would have played a key role as a refuge in periods of major environmental change during the latest Cretaceous, which caused the extinction of other vertebrate lineages. Over the evolutionary history of Neornithes, diverse dispersal and colonization events have been fundamental for subsequent vicariance episodes and diversification within bird lineages. Diverse moments of dispersion events would configure the macroevolutionary patterns of birds. The first one, during the late Upper Cretaceous where the ancestors of land-cursorial and aquatic lineages Paleognathae, Galloanseres and Aequornithes disperse from South America to Africa, Antarctica and North America. Likewise, a second wave of diversification would have occurred along the late Paleocene and early Eocene. This event allowed the diversification of bird families with tree-dwelling habits and prominent fly capacity as diverse lineages within Caprimulgiformes and Afroaves. The patterns obtained suggest

a possible relationship between these processes and the expansion of tropical ecosystems at high latitudes during this period. Later, during the Oligocene, significant global changes conditioned the appearance of novel seasonal and open biomes due to global cooling trends. According to the above, our results suggest that the emergency of these new niches promoted a new pulse of dispersion in marine and land-cursorial lineages. During this period, diverse shorebirds and seabirds (Procellariiformes and Charadriiformes) and modern lineages of fowls (Galliformes), bustards (Otidiformes) and other lineages adapted to open environments showing a prominent diversification. Finally, during the Miocene and Pliocene, with the intensification of seasonal patterns in the Northern Hemisphere, important retraction events in tropical forests towards equatorial latitudes caused the extinction of many bird families in emerging seasonal temperate environments, which confined their distributions to Pantropical biomes.

The chapter 4 explores the historical process of biome occupation considering a phylogenetic perspective. This allowed integrating evolutionary hypotheses as niche conservatism into the biome historical dynamics. As we highlight in Chapter 2, the biomes are consolidated as key ecological units for macroevolution and macroecological studies, due to their structure and history, which is closely connected to climatic variables and geological processes. In addition, the implicit phylogenetic signal in the taxa provides the opportunity to study the influence of biome dynamics and the processes of adaptation to climate regimes under deep-time perspective. For this, we used recently-developed analytical techniques based on phylogenetic information to reconstruct the historical occupation of climatic "evolutionary arenas".

Galliformes and Falconiformes are distributed worldwide. Moreover, these groups have evolved adaptations linked to their different trophic strategies: herbivores and faunivores respectively. The extensive knowledge of their phylogenetic relationships at the species-level and the vast ecological information available allowed us to study their historical dynamics in biome occupancy. In this way, we aimed to clarify what environmental factors were critical in this occupation patterns and what are the main trends in the evolution of the climate niche by assessing the phylogenetic conservatism at the scale of biomes.

Finally, the results of this chapter are broadly consistent with phylogenetic niche conservatism in both groups. The biome conservatism was particularly marked in

biomes of extreme conditions within the climatic gradient. Thus the findings reflect the development of specific morphological and physiological features to colonize these environments, which tend to constrain subsequent colonization events. Similarly, our findings suggest that the different climate changes occurred during the Miocene triggered the main diversification pulses in both groups. During this period, the adaptation and wide occupancy of seasonal dry biomes such as tropical dry forest and savanna would have allowed the subsequent colonization of other biomes, in tropical and temperate latitudes. The findings suggest the important role as "species source" of the tropical deciduous woodland, which consolidate this biome as important player in diversification processes.

Conclusions

Overall, our results provide a holistic view of the important role played by global climate changes and tectonic processes in structuring living non-passerine birds diversity and disparity. Our approach shows the great importance of the study of modern faunas and their phylogenetic relationships to obtain evolutionary inferences of high explanatory power. Finally, this study opens a new perspective that integrates neontological and paleontological data in a historical context for understanding and shed valuable light about the complex evolutionary process of modern birds lineages since their origin until our days.

1 Introducción

Introducción 1

"Seeing this gradation and diversity of structure in one small, intimately related group of birds, one might really fancy that from an original paucity of birds in this archipelago, one species has been taken and modified for different ends"

Charles Darwin (1845)

"New evolution research ruffles some feathers"

Mark Norrell (1996)

Desde su origen en el Jurásico Superior las aves se han diversificado exitosamente logrando colonizar todos los ambientes del planeta Tierra (Cracraft 1986; Padian & Chiappe 1998; Chiappe & Witmer 2002; Del Hoyo et al. 1992-2002; Jetz et al. 2012). A lo largo de su historia han desarrollado una gran variedad de adaptaciones que les ha permitido ocupar nichos ecológicos de diverso tipo; desde polinizadoras como los colibríes, dispersoras de semillas como las palomas, pasando por especies ictiófagas, insectívoras e incluso carroñeras. Muchos de estos nichos han permitido a las aves un papel fundamental en numerosas relaciones de coevolución con otras especies en los ecosistemas, como en el caso de diversas especies polinizadoras y dispersoras de semillas que se han diversificado a partir de la evolución paralela ave-planta en ambientes tropicales (Wheelwright 1985; Gill 2007;

Cronk & Ojeda 2008; Pettingill 2013). Con cerca de 10000 especies, la diversidad de las aves en la actualidad es muestra de su destacado éxito evolutivo entre los vertebrados, y sin lugar a dudas esta predominancia ecológica es debida en gran medida al desarrollo de la capacidad voladora (Ksepka 2014). Asimismo, características como sus hábitos principalmente diurnos, ser frecuentes y activos voladores en muchos ecosistemas, así como su estética llamativa fueron factores decisivos que consolidaron a las aves como objeto de estudio preferente por los primeros naturalistas, que se maravillaron con la investigación de todo lo que las rodeaba (Audubon 1843; Birkhead & Charmantier 2001; Egerton 2003; Haffer 2008). De esta manera, las aves han llegado posiblemente a ser el grupo de vertebrados mejor estudiado en términos de su ecología, comportamiento y distribución geográfica.

1. El estudio de la evolución en las aves.

Desde las descripciones de Linneo, pasando por los estudios de Humboldt en Sudamérica o Wallace en el Sudeste Asiático, hasta los míticos pinzones de Darwin (Birkhead & Charmantier 2001), las aves históricamente se han convertido en un grupo modelo para el estudio de diversos procesos evolutivos (Mayr 1940; Cracraft 1985a; McKitrick & Zink 1988; Block & Brennan 1993; Fjeldså 1994; Holmes & Austad 1995; Gottschalk et al. 2005; Grant & Grant 2006; Cardillo et al. 2005; Chesser & Zink 1994; Jetz et al. 2008; Phillimore et al. 2008; Lanfear et al. 2010). Muchos estudios se realizaron en el pasado y también en la actualidad acerca de sus dinámicas ecológicas, patrones de migración, variación intraespecífica y genética poblacional, así como de los patrones de especiación y extinción, relaciones filogenéticas, entre otros muchos aspectos de su biología (Martin 1995; Marshall 2013; Schreiber and Burger 2001; Newton 2003; Berthold et al. 2003; Jetz et al. 2012; Jarvis et al. 2014). Sin embargo, desde el punto de vista de los estudios de la paleontología de las aves, algunos de los principales avances son relativamente recientes, la gran mayoría de ellos de los últimos 20 años (Gauthier and Gall 2001; Chiappe and Witmer 2002; Mlíkovský 2002; Mayr 2009; O´Connor and Zhou 2013; Lee et al. 2014). Durante décadas los únicos conocimientos destacados sobre la paleontología y las relaciones filogenéticas de las aves fueron los referentes a su ancestro *Archaeopteryx lithographica* (Heilmann 1926; Ostrom 1974, 1976) o a los

hallazgos y estudios de aves mesozoicas como *Ichthyornis* y *Hesperornis* hechos en Norteamérica (Gregory 1952; Gingerich 1972; Gingerich 1973).

La historia de *Archaeopteryx* comienza a mediados del siglo XIX cuando Richard Owen realiza la descripción (Owen 1863) del que sería históricamente fundamental en el respaldo de la misma teoría evolutiva (Darwin & Wallace 1858) y por mucho tiempo el icono de la evolución. Aunque adecuadamente clasificado por Owen como un ave, tendría que llegar Thomas H. Huxley para que tras un estudio detallado se planteara su naturaleza "reptiliana" (Huxley 1868). Con esta evidencia de ancestría para las aves, Huxley se dio a la tarea de encontrar "parentescos" comparando diversos reptiles mesozoicos encontrados hasta ese momento. Él identificaría importantes similitudes anatómicas entre el terópodo *Compsognathus* y *Archaeopteryx* (Huxley 1870). Esta comparación sería revolucionaria para la época y fundamental para posteriores estudios morfológicos (Chiappe & Witmer 2002; Mayr et al. 2005).

La idea del origen dinosauriano de las aves quedaría relativamente rezagada a consecuencia de los estudios de Heilmann (1926) e incluso por el mismo Huxley (1870), quienes no apoyarían la descendencia terópoda de las aves debido a la ausencia de clavículas en los terópodos y la presencia de las mismas a modo de fúrcula en las aves. De esta manera, por mucho tiempo se consideró un origen a partir de grupos basales de reptiles diápsidos (origen tecodonto). Sin embargo, la visión de las aves como dinosaurios seguiría latente desde Huxley y sería posteriormente retomada por algunos investigadores a la luz de nuevos descubrimientos. En la década de los 70 las comparaciones anatómicas que realizó Ostrom (1976) con el recientemente descrito dinosaurio *Deinonychus* pondrían de manifiesto de nuevo muchas similitudes morfológicas entre estos terópodos y las aves. Asimismo, posteriormente se realizarían hallazgos de numerosos dinosaurios terópodos que aportaron nueva información morfológica y arrojarían mayor luz al estudio de las relaciones evolutivas existentes entre terópodos y sus descendientes actuales, las aves (Ostrom 1976; Qiang et al. 1998; Sereno 1999; Chiappe & Witmer 2002; Göhlich & Chiappe 2006; Zhang et al. 2008).

En los últimos años, importantes evidencias han logrado aportar indicios acerca del desarrollo de las características que definen típicamente a las aves, como es el caso del plumaje (Prum & Brush 2002; Longrich 2006; Zelenitsky et al. 2012; Clarke 2013; Zheng et al. 2013; Foth et al. 2014; Zhou 2014; Feo et al. 2015). Este

carácter actualmente es considerado como plesiomórfico dado su registro para diversos dinosaurios terópodos en los que se han encontrado desde estructuras filamentosas similares a la filopluma hasta incluso plumas en el sentido moderno estructuralmente hablando (Norell et al. 2002; Xu et al. 2009; Xu et al. 2010; Clarke 2013; Foth et al. 2014). Estos hallazgos integrados a nuevos análisis filogenéticos han llevado a relacionar aves con los linajes terópodos dromaeosauridos y troodontidos (Foth et al. 2014). En la medida que más caracteres se suman como plesiomorfías de las aves con respecto a sus ancestros (O'Connor & Claessens 2005; Salvador & Fiorelli 2011; Benson et al. 2014), resulta incuestionable el replanteamiento de la monofilia tradicional e histórica del grupo. Considerando lo anterior, (Chiappe 2002) define tres sinapomorfías para las aves: 1) El margen posterior de foramen nasal llega o se superpone al borde anterior de la fosa anteorbital; 2) La escápula presenta un acromion destacado, y 3) El proceso postacetabular es poco profundo y puntiagudo, menos del 50% de la profundidad del ala preacetabular. Queda así definido el clado Avialae como aquel que incluye a *Archaeopteryx* y a todos sus descendientes (Turner et al. 2012).

1.1. *Archaeopteryx y la diversificación de sus descendientes durante el Mesozoico*

Filogenéticamente las aves son dinosaurios terópodos, y *Archaeopteryx*, además de ser un icono de la paleontología por el excepcional estado de preservación de sus 12 especímenes (Mayr et al. 2007; Callaway 2014; Foth et al. 2014), ha conservado por cerca de 150 años su posición de "primer ave", la cual ha sido cuestionada por hallazgos recientes como el de *Aurornis xui* en China (Godefroit et al. 2013; Callaway 2014). Sin embargo, y aunque *Archeopteryx* sea relevado por futuros hallazgos, durante muchos años el análisis de sus fósiles ha aportado una valiosa información sobre los procesos evolutivos durante la transición dinosaurio-ave (Brusatte et al. 2014; Callaway 2014; Foth et al. 2014; Ksepka 2014). Por tanto, su estudio seguirá siendo fundamental para comprender los procesos de cambio morfológico y adaptativo que llevaron a las aves a consolidarse en lo que son actualmente. De esta manera, ha sido posible obtener un amplio abanico de información anatómica que ha permitido realizar análisis filogenéticos entre *Archaeopteryx* y el creciente número de formas Mesozoicas que han hecho su aparición en el registro fósil como *Jeholornis* o

Confuciusornis (Chiappe et al. 1999; Zhou & Zhang 2003), presentando una condición relativamente basal en comparación a otros linajes más derivados como Enanthiornithes y Ornithurines (Chiappe & Witmer 2002; O'Connor & Chiappe 2011; Lee et al. 2014).

Una de las características más notorias de *Archaeopteryx* es su plumaje, el cual se caracteriza por una organización estructuralmente similar a la observada en las aves modernas, con un raquis y un véxilo asimétrico. Al igual que en las aves actuales presenta de 11 a 12 plumas primarias y de 12 a 15 secundarias (Elzanowski 2002). La presencia de estos caracteres ha hecho que la capacidad voladora de *Archaeopteryx* sea tema de debate y diversos estudios (Chatterjee & Templin 2003; Burnham 2007; Foth et al. 2014). Sin embargo, parece claro que el análisis de muchas características anatómicas son un componente clave para estudiar el origen del vuelo (Pelegrin 2010). Mientras que algunos autores debaten si la articulación de sus alas les habría permitido batirlas por encima del cuerpo (Senter 2006), diversos análisis de su posible capacidad pulmonar (Christiansen & Bonde 2000; O'Connor & Claessens 2005), metabolismo a partir de estructura esquelética (Erickson et al. 2009) y estructura neurosensorial (Alonso et al. 2004) sugieren una destacada capacidad voladora. Por otra parte, también se ha sugerido que los ancestros de *Archeopteryx* eran un animales predominantemente terrestres y que el vuelo habría surgido desde el suelo a partir de una actividad corredora. Frente a esto, Mayr (Mayr et al. 2005) reporta que el hallux de *Archaeopteryx* esta orientado de forma distinta respecto a especies arborícolas, lo que implicaría una forma de vida terrestre. Por el contrario, autores como Feduccia (1999) analizando la curvatura de las garras propone un contexto arbóreo para la evolución del vuelo (Chatterjee & Templin 2003; Burnham 2007).

El hallazgo de dinosaurios maniraptores (*Microraptor gui*) con plumaje desarrollado y posiblemente apto para el vuelo en las extremidades posteriores (Xu et al. 2003; Xu and Zhang 2005; Chatterjee & Templin 2007; Zheng et al. 2013) así como nuevos análisis de *Archaeopteryx* (Longrich 2006; Foth et al. 2014) y otras aves mesozoicas (e.g. *Sapeornis*) han permitido proponer un escenario en donde el vuelo surge a partir de dinosaurios planeadores y con una destacada vida arborícola y una condición "tetralar" (Longrich 2006; Chatterjee & Templin 2007; O'Connor et al. 2011). Posteriormente con el desarrollo del vuelo activo en el linaje de *Archaeopteryx*,

el plumaje de las patas posteriores habría sufrido una reducción considerable hasta consolidarse evolutivamente la condición bialar (Longrich 2006; Zheng et al. 2013). Finalmente, a la luz de las actuales evidencias, parece razonable afirmar que la evolución del vuelo en las aves tiende aún más a explicarse estableciendo matices adaptativos y no un simple juego de hipótesis dicotómicas.

En los últimos años el registro fósil de las aves de periodos mesozoicos ha sufrido un aumento considerable (Chiappe & Dyke 2002). Grupos como Enantiornithes, de importante presencia durante el Cretácico, han sido encontrados en Argentina, España y especialmente China (Chiappe 1995; Sanz et al. 1996; Chiappe & Witmer 2002; Sanz & Ortega 2002; Zhou & Zhang 2007; Li et al. 2010), evidenciando así el alto grado de dispersión que alcanzaron las primeras aves. Diversos descubrimientos han logrado aportar importantes datos sobre la evolución de la morfología, la dieta e incluso lograr inferir posibles rasgos comportamentales de muchas especies extintas de aves (Zhou & Zhang 2007; Li et al. 2010; Naish 2014; Pelegrin et al. 2014b). De esta manera se ha mejorado sustancialmente el conocimiento de la inicial diversificación de las aves y su relación con la adquisición de ciertos caracteres anatómicos e innovaciones evolutivas que serían fundamentales en el éxito ecológico de las aves modernas.

1.1.1. Ornithothoraces: Enantiornithes

Ornithothoraces hace referencia al clado que incluye a los ancestros de Enantiornithes y Euornithes y a todos sus descendientes (Fig.1). En este linaje se evidencia una mayor tendencia hacia la fusión esquelética con el desarrollo del tarsometatarso y carpometacarpo, así como la modificación estructural del esternón y la presencia del álula lo que sugiere un vuelo mucho más activo en estos linajes que en sus contrapartes más primitivas. Enantiornithes (*Aves opuestas*) recibe su nombre por la condición contraria presente en la articulación del coracoides y el esternón en la cintura escapular respecto a las Euornithes (Walker 1981), en estas últimas la escapula presenta una prominencia que se ajusta al coracoides, condición que es contraria en los Enantiornithes, en los cuales se articula el coracoides con la escapula (Chiappe et al. 2002). Su estructura craneal presenta caracteres relacionados con la poca fusión ósea como la presencia de un hueso postorbital o la conservación de un dentario no bifurcado (O´Connor & Chiappe 2011). Asimismo, poseen una

estructura premaxilar y maxilar con dientes, concentrados en muchas especies en los extremos de la boca (Louchart & Viriot 2011; Turner et al. 2012).

Con cerca de 60 especies descritas, Enanthiornites posiblemente fue el grupo de aves más exitoso durante el Cretácico con respecto a las primeras Euornithes (Longrich et al. 2011) y ocuparon todos los continentes exceptuando la Antártida (Chiappe et al. 2002; O'Connor 2009). Pese a su relativa uniformidad anatómica, esta amplia distribución geográfica da idea de su grado de dispersión lo que ha llevado a muchos autores a compararlas con las actuales paseriformes (Chiappe & Dyke 2002; Chiappe 2007; O'Connor et al. 2013). Sin embargo otros autores sugieren que su disparidad ecológica pudo estar inicialmente restringida por los pterosaurios, reduciendo posiblemente su presencia a ciertos ambientes y ecoespacios, lo cual sería consistente con una radiación inicial durante el Cretácico en algunos nichos específicos, pero no muy diversos en comparación a los que llenarían los representantes de Euornithes (específicamente Neornithes) durante el Cenozoico (Mitchell & Makovicky 2014).

Características anatómicas como la presencia de hallux oponible, la retención de garras en las extremidades anteriores así como hallazgos que han permitido inferir su dieta, han sugerido que los Enantiornithes eran principalmente aves de hábitos terrestres dominantes en ambientes forestales donde presentarían una amplia gama de hábitos alimenticios que irían desde partes blandas de vegetales como en *Pengornis houi* (O'Connor & Chiappe 2011) o insectos como *Sulcavis geeorum* (O'Connor et al. 2013). Igualmente, parece ser que algunos linajes pudieran haberse especializado en ser rapaces (i.e *Bohaiornis*) o en la captura de peces en ambientes lacustres (i.e *Longipteryx chaoyangensis*) (Hou et al. 2004; Li et al. 2014; Wang et al. 2014). Esto las convertiría en importantes componentes de los ecosistemas cretácicos hasta su extinción en el evento Cretácico/Paleógeno (Longrich et al. 2011).

1.1.2. Euornithes = Ornithuromorpha

Este clado engloba a todos los linajes de aves más cercanas a las actuales Neornithesque Enantiornithes (Turner et al. 2012). Una de las principales innovaciones evolutivas que presentan las primeras Euornithes es un mayor estado de reducción y modificación del pigóstilo que les permitiría una cola con plumaje en

forma de abanico (Fig.1). Esta estructura sería bastante similar respecto a las formas modernas (Neornithes), representando una importante ventaja adaptativa en términos de maniobrabilidad durante el vuelo (Martyniuk 2012; O´Connor & Zhou 2013). A diferencia de Enanthiornithes, Euornithes desarrolla una estructura de pico homologa a la de Neornithes. Sin embargo, al igual que en muchos linajes basales de Avialae se presenta una importante retención de dientes en las mandíbulas y por consiguiente, el desarrollo del pico estará restringido a la región más distal de las mandíbulas (Zhou & Zhang 2006). Esta condición dentada en las formas más basales de Euornithes estará asociada al hueso predentario en la mandíbula inferior y será perdida completamente en las aves modernas (Louchart & Viriot 2011; Meredith et al. 2014).

El análisis ecológico de la abundancia y estructura anatómica de los primeros Euornithes ha llevado a sugerir un modo de vida acuático como condición ancestral para este grupo, esto se ha evidenciado en la asociación de muchos de los ejemplares encontrados con ambientes acuáticos del pasado (Longrich 2009). Igualmente, dada la presencia de mandíbulas predominantemente dentadas de estas formas, asociándolas con la captura de peces e invertebrados o el hallazgo de ejemplares con adaptaciones especializadas a modo de lamelas para dietas más herbívoras (Zhou & Zhang 2005, 2006). Esto ha permitido plantear un escenario en donde los linajes de Enantiornithes habrían sido abundantes en los ambientes continentales, mientras que los de Euornithes por su parte habrían estado asociados a ambientes acuáticos (Longrich 2009; You et al. 2006; Wang et al. 2015).

1.1.3. Euornithes derivados: Ornithurae

Ornithurae es un clado que contiene a *Gansus* y todos sus descendientes (Dalsätt 2012), estos linajes estarían más próximos a Hesperornithiformes y al clado Carinatae (Fig.1), este último conformado por el linaje de las aves Ichtyornithes y el de las aves Neornithes como grupos hermanos (Turner et al. 2012). El establecimiento monofilético de Ornithurae esta sustentado por diversas sinapomorfías como: disminución en el número de vertebras torácicas y fusión de vertebras sacras formando el sinsacro; pubis e isquion más o menos paralelos y dirigidos posteriormente; reducción del acetábulo; diversos caracteres asociados a los metatarsos; y un destacado ensanchamiento del esternón para el posterior desarrollo

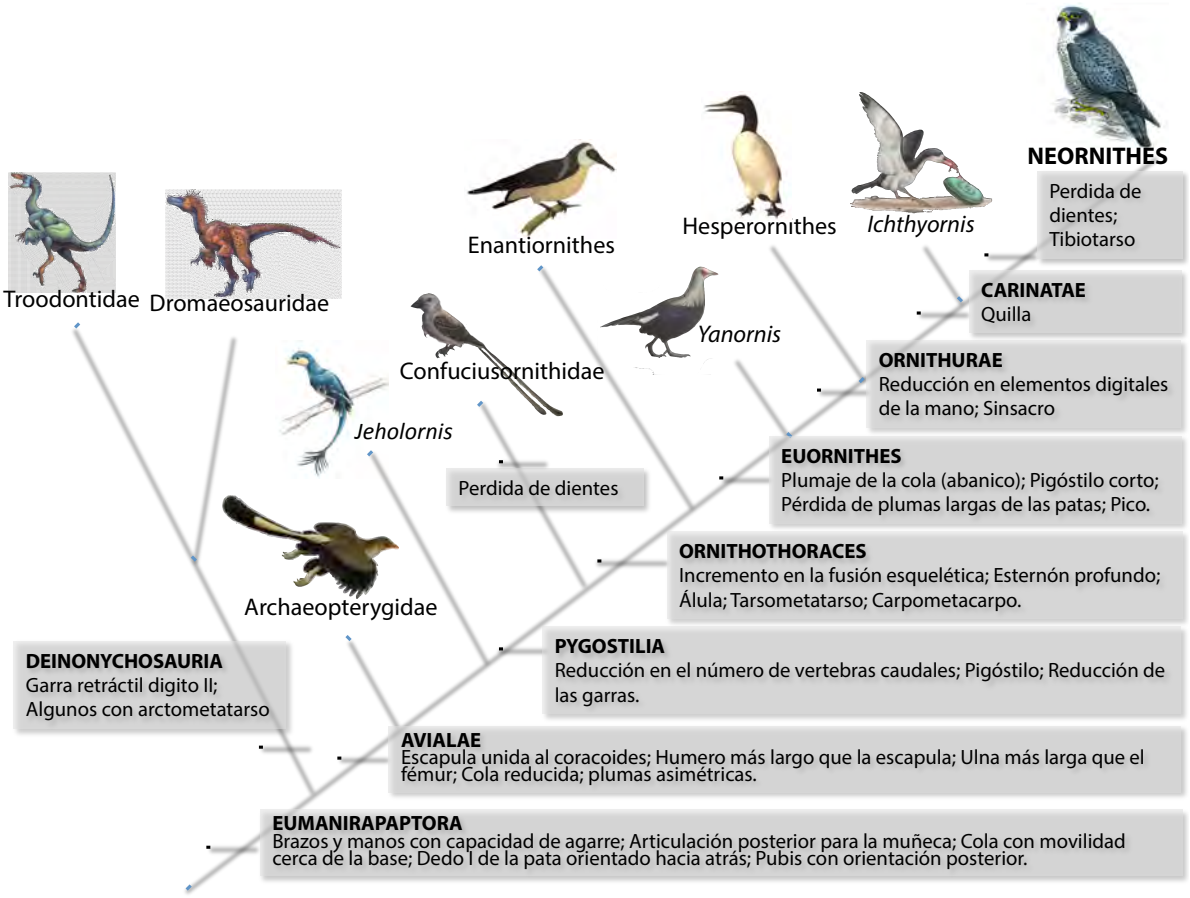


Figura 1. Principales clados de aves y sus sinapomorfías más relevantes.

de una quilla para inserción muscular. Este último rasgo anatómico sería definitorio del clado Carinatae, en dónde sería mucho más destacado dada su importancia funcional. Asimismo este linaje desarrollaría otras innovaciones evolutivas que se pueden apreciar en las aves actuales como lo son el desarrollo de un cráneo globoso o la fusión metacarpal completa (Chiappe & Dyke 2002; Dalsätt 2012).

La gran mayoría de los miembros cretácicos de Ornithurae serían formas predominantemente acuáticas (Longrich 2009; Wang et al. 2015). *Gansus yumenensus* del Cretácico Inferior (115 – 105 Millones de años), uno de los miembros más antiguos del clado, posee características anatómicas que sugieren una capacidad natatoria que semejarían funcionalmente a los zampullines actuales (You et al. 2006; Dalsätt 2012; Wang et al. 2015). Por otra parte, los Hesperornithiformes con cerca de 20 especies descritas y una distribución geográfica restringida al Hemisferio Norte durante el Cretácico Superior, representan el primer grupo de aves en el registro fósil

con una morfología fuertemente hidrodinámica. Esto ha sugerido una evolución de este linaje en estrecha asociación con una vida acuática estricta, similar a los actuales colimbos (Martin 1984; Rees & Lindgren 2005; Bell & Everhart 2009; Wilson et al. 2011).

Dentro del clado Carinatae, el linaje Ichtyornithiformes estuvo representado por especies de una morfología similar a la que podría encontrarse en las gaviotas actuales, esto ha sugerido una ecología y hábitos convergentes (Clarke 2004). *Ichthyornis* y otras especies habrían tenido una destacada presencia en los ecosistemas costeros y marinos del Cretácico Superior donde se habrían alimentado de peces e invertebrados (Chiappe & Witmer 2002; Clarke 2004; Dalsätt 2012). A pesar de la presencia de dientes (Martin & Stewart 1977), podría decirse que su anatomía era prácticamente moderna y habría sido probablemente una especie con una capacidad voladora altamente desarrollada (Clarke 2004).

1.2. Neornithes: Las aves modernas

1.2.1 Los Neornithes durante el Cretácico

Neornithes representa el clado que incluye por los linajes del "*crown group*" Avialae que viven en la actualidad y sus parientes más próximos extintos durante el Cenozoico (Mayr 2009). Se caracterizan fundamentalmente por cerca de 11 sinapomorfias craneales y poscraneales, algunas de las cuales son: la perdida completa de los dientes, la presencia de un coracoides neumatizado o el desarrollo de un tibiotarso (Turner et al. 2012). En términos de su registro fósil, los hallazgos de Neornithes durante el Cretácico Superior son escasos, limitados a pocos elementos anatómicos o compuestos por restos fragmentarios que no han permitido una fiable reconstrucción de su posible apariencia o establecer hipótesis sobre las relaciones filogenéticas de estos ejemplares con respecto a los linajes de Neornithes conocidos (Hope 2002; Chiappe & Dyke 2006). Pese a esta relativa poca abundancia, algunos de los especímenes encontrados han sido tentativamente asignados a grupos presentes en la actualidad, como el caso de *Vegavis* y *Presbyornis* emparentados con los Anseriformes (Livezey 1997; Clarke et al. 2005), *Austinornis* con los Galliformes o *Polarornis* posiblemente miembro del linaje Gaviiformes (Mayr 2009, 2014).

A partir del Paleoceno el registro fósil de Neornithes aumenta considerablemente (Olson 1985; Mayr 2009), planteando una amplia discusión relacionada con el *tempo y modo* de su diversificación y radiación adaptativa (Chiappe & Dyke 2006; Ericson 2008; Padian & de Ricqlès 2009). Bajo este contexto se han formulado dos hipótesis fundamentales. Por un lado, existe un punto de vista según el cual los linajes basales de Neornithes habrían sobrevivido a la crisis de finales del Cretácico para dar origen a una radiación adaptativa rápida a inicios del Paleogeno (Feduccia 1999; Feduccia 2003). Estos linajes de aves basales estarían representados por especies de aves adaptadas a ambientes costeros (Feduccia 2003). Por otra parte, diversos autores argumentan que los ancestros de los principales clados modernos habrían tenido su origen ya en el Cretácico Superior (Cooper & Penny 1997; Chiappe & Dyke 2006; Penny & Phillips 2004; Longrich et al. 2011). Con respecto a lo planteado, es importante anotar que tanto la evidencia fósil (Lee et al. 2014; Mayr 2014) como los más recientes estudios moleculares (Ericson et al. 2006; Hackett et al. 2008; Pacheco et al. 2011; Jarvis et al. 2014), establecen un origen para los grupos modernos de Neornithes en el Cretácico. De esta manera es posible generar una explicación que contraste las hipótesis en un escenario evolutivo en el cual probablemente los linajes de Neornithes mantendrían niveles bajos de diversidad a finales del Mesozoico por la competencia interespecífica con otros linajes de Ornithurae e incluso de Enantiornithes, Theropoda y Pterosauria (Cooper & Fortey 1998). Igualmente, algunos autores sostienen que la evolución inicial de Neornithes pudo darse en el Hemisferio Sur, esto explicaría la poca abundancia en el registro cretácico debido a importante sesgo de muestreo. Asimismo, el proceso de evolución inicial de Neornithes habría estado potenciado por el proceso de fragmentación de Gondwana durante el Cretácico, con una posterior colonización del Hemisferio Norte durante el Paleógeno (Cooper & Fortey 1998; Cracraft 2001; Ericson et al. 2002; Ericson 2012).

1.2.2. Relaciones filogenéticas de las aves modernas

Desde Linneo, la sistemática y el posterior estudio de la evolución de las aves se basó en su similitud morfológica, de esta manera se llegaron a consolidar grupos (ordenes y familias) establecidos a partir de caracteres relacionados con la estructura del pico, las proporciones de las extremidades o la configuración y disposición de los

dedos en las patas (Birkhead & Charmantier 2001; Gill 2007). Con la introducción de las técnicas de análisis filogenético por similitud genética se presentó la oportunidad de conocer las relaciones evolutivas de las aves más allá de su morfología, la cual en muchos casos es el resultado de procesos de convergencia evolutiva (van Tuinen et al. 2001; Ericson 2012). Los estudios sistemáticos a partir de la hibridación del ADN realizados por Sibley y Ahlquist serían pioneros en la inclusión de datos moleculares para la inferencia de las relaciones filogenéticas en las aves a una gran escala taxonómica (Sibley & Ahlquist 1983; Sibley et al. 1988; Sibley & Ahlquist 1990). Estos análisis plantearían nuevos retos a la sistemática tradicional y abrirían toda una línea de investigación hacia análisis cada vez más complejos y con un mayor grado de resolución.

Los resultados de los análisis moleculares presentan una alta fiabilidad dada la independencia de la información de partida, como es el caso de los realizados a partir de ADN mitocondrial y nuclear (Houde 1987; Groth & Barrowclough 1999; Braun & Kimball 2002; García-Moreno et al. 2003; García-Moreno 2004; van Tuinen et al. 2004). Durante los últimos años una gran variedad de estudios moleculares han contribuido a esclarecer las relaciones evolutivas, así como a aportar indicios acerca del posible origen y radiación de los grandes grupos de aves (van Tuinen et al. 1998; Härlid & Arnason 1999; van Tuinen et al. 2000; Haddrath & Baker 2001; Barker et al. 2002; Paton et al. 2002; Fain & Houde 2004; van Tuinen et al. 2004; Pereira et al. 2007). Sin embargo, a pesar de la gran importancia de los estudios moleculares sólo en tiempos recientes se ha incluido información proveniente del registro fósil, la cual implica una integración entre la morfología y la información molecular (Ericson et al. 2006). El estudio morfológico permite establecer la relación evolutiva del espécimen fósil (Mayr 2014), y a su vez, sólo la información fósil puede proporcionar un marco temporal a las filogenias moleculares (van Tuinen & Hedges 2001; Ksepka et al. 2014; Mayr 2014).

A partir de los estudios moleculares se han consolidado tres grandes clados dentro de Neornithes. La divergencia inicial se presenta entre el linaje Paleognathae, representado por ratites y tinamúes, y el linaje Neognathae con los demás grupos de aves modernos (van Tuinen et al. 1998; Härlid & Arnason 1999; Hackett et al. 2008; Harshman et al. 2008; Baker et al. 2014). Este último a su vez estaría compuesto por los clados Galloanserae (gallinas, patos y afines) y Neoaves, que incluiría a la gran

mayoría de grupos actuales (Fig.2). Las relaciones filogenéticas de estos clados basales serían consistentes con las obtenidas en estudios morfológicos (Mayr & Clarke 2003; Mayr 2007; Livezey & Zusi 2007). Las discrepancias entre los diversos tipos de estudios se han presentado cuando se han realizado análisis filogenéticos morfológicos que pretenden analizar las relaciones evolutivas a gran escala y con una extensiva cantidad de caracteres. Sin embargo, pese a la poca consistencia de muchos de ellos con respecto a las propuestas moleculares, estos análisis han sido fundamentales para establecer sinapomorfias en los diversos clados que permiten una mejor identificación de los fósiles y su correcta asignación sistemática (Mayr 2007,2009, 2014).

Mientras las relaciones basales de Neornithes están relativamente bien establecidas, la sistemática de Neoaves ha sido materia de amplia discusión. Con numerosos análisis e intentos de resolver estas relaciones se estableció una divergencia de Neoaves en "Coronaves" y "Metaves" (Fain & Houde 2004). Sin embargo, dado que fueron realizados con un único marcador molecular, estos estudios fueron ampliamente cuestionados por su bajo nivel de confianza (Ericson 2008). Posteriormente se realizarían análisis considerando más datos moleculares y además integrarían esta información con fósiles para construir una propuesta consensuada. Ericson et al. (2006) a partir de un estudio de cinco genes nucleares complementado con información fósil, sugieren una primera aproximación a las relaciones evolutivas de los principales grupos incluidos en Neoaves (Ericson et al. 2006). Posteriormente estos resultados serían respaldados en el análisis realizado por Hackett et al. (2008) para 19 *loci* independientes en 169 especies (Hackett et al. 2008). Ambos trabajos pondrían de manifiesto la condición polifilética de muchos linajes considerados tradicionalmente como monofiléticos, como en el caso de las aves rapaces diurnas, ahora en dos ordenes: Accipitriformes y Falconiformes, la condición anidada del grupo Apodiformes (vencejos y colibríes) dentro de lo que clásicamente fue considerado Caprimulgiformes (chotacabras) o la reestructuración de las relaciones entre los clados de aves acuáticas Ciconiformes (cigüeñas), Pelecaniformes (pelicanos y garzas) y el recién creado Suliformes (alcatraces y fragatas). Asimismo, estas investigaciones, como muchas anteriormente mencionadas respaldarían un origen Cretácico para los principales clados de Neornithes (van Tuinen & Hedges 2001; Ericson et al. 2006; Hackett et al. 2008; Pacheco et al. 2011; Lee et al. 2014).

A lo largo de la última década se han publicado diversas propuestas filogenéticas que incluyen un número relativamente alto de especies para muchos grupos de aves; Galliformes y Anseriformes (Eo et al. 2009; Stein et al. 2015), Apodiformes (McGuire et al. 2014), Falconiformes (*sensu lato* Wink et al. 1998; Griffiths et al. 2004) y (*sensu stricto* Fuchs et al. 2015), Psittaciformes (Tavares et al. 2006; Schweizer et al. 2010), Piciformes (Webb & Moore 2005; Fuchs et al. 2006), Passeriformes (Barker et al. 2004; Jønsson & Fjeldså 2006), entre otros (Friesen & Anderson 1997; Thomas et al. 2004). La creciente cantidad de información filogenética dentro de los diversos grupos y los análisis a gran escala de Ericson et al. (2006) y Hackett et al. (2008), permitieron que Jetz et al. (2012) realizarían una pro puesta filogenética con todas las especies de aves actuales analizando sus tasas de diversificación en el tiempo y el espacio. A pesar de constituirse como la primera gran aproximación hacía una visión filogenética general, esta no alcanzaría suficiente soporte estadístico en muchos de sus clados (Jetz et al. 2012).

Con un promedio de 1.45 miles de millones de pares de bases y siendo de los más pequeños entre los vertebrados, el genoma de las aves representa una importante fuente de información en términos de sus regiones no codificantes (Gregory 2002; Lanfear et al. 2010). Diversos estudios han sugerido que el tamaño del genoma se correlaciona con altas tasas metabólicas y que probablemente se presentó una destacada tendencia hacia su disminución en los linajes de dinosaurios saurisquios, especialmente en los linajes de terópodos carnívoros de los cuales las aves descienden (Organ et al. 2007; St John et al. 2012). Lo anterior revela la importancia que representa el análisis del genoma completo en el establecimiento de las relaciones evolutivas de las aves. Considerando esto, no sería hasta finales del año pasado cuando Jarvis et al. (2014) plantearían una filogenia que incluiría el análisis completo del genoma para 48 especies de aves, representando todos los principales grupos taxonómicos a escala de orden (Fig. 2). Con esta aproximación filogenética se logró consolidar lo propuesto en hipótesis anteriormente publicadas con respecto a ciertas relaciones basales, así como arrojar mayor luz sobre la resolución de diversas relaciones debatidas. Esta última propuesta ha sido la considerada como base filogenética para el desarrollo de este trabajo de Tesis Doctoral.

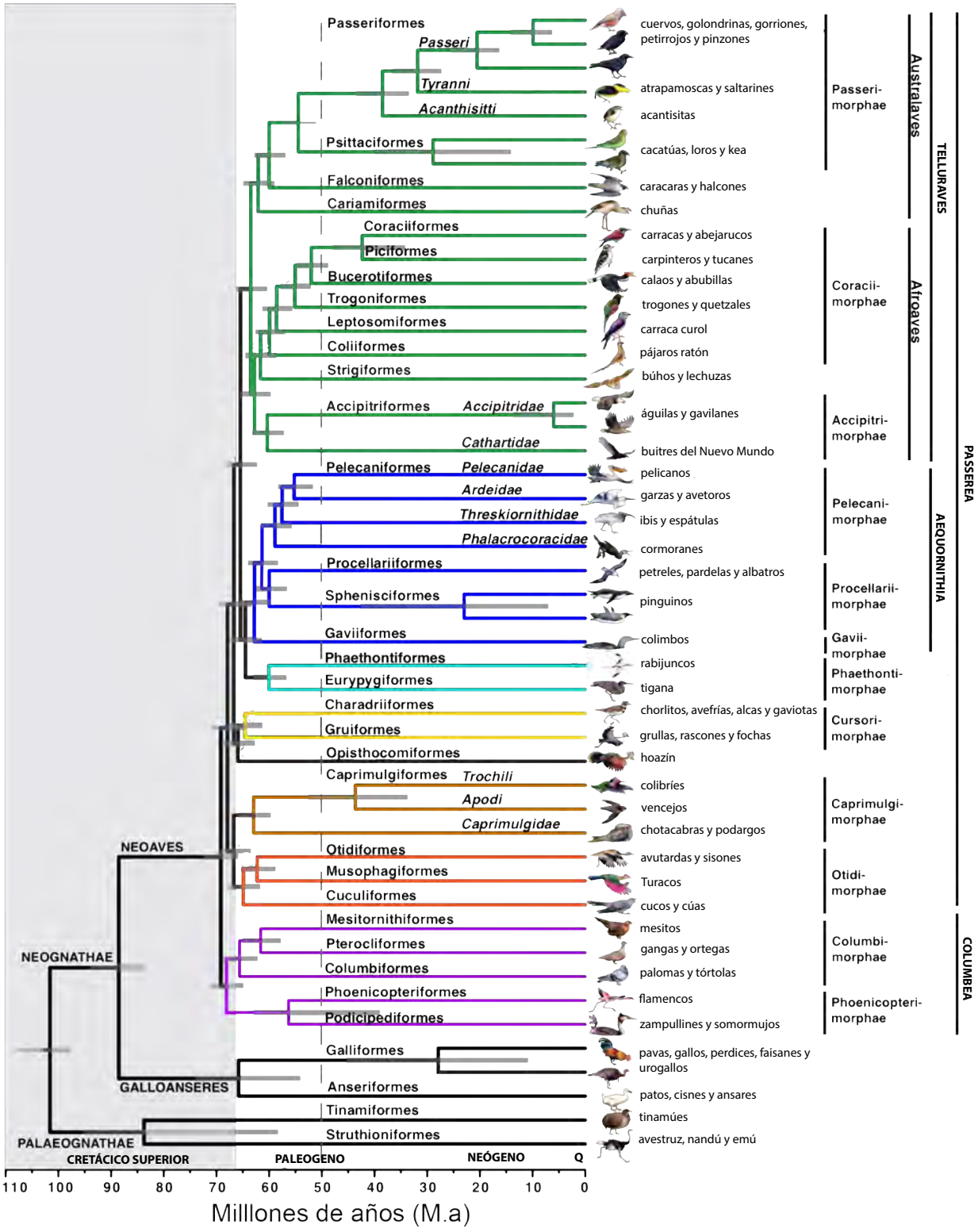


Figura 2. Propuesta filogenética de Jarvis *et al*. (2014) que resume los grupos de estudio de esta Tesis Doctoral y las relaciones evolutivas fundamentales consideradas para los diversos análisis. Q, Cuaternario. (*Modificado de Jarvis et al. 2014*).

2. Contexto filogenético, ecológico y paleontológico en macroevolución.

Inspirados en la figura de G.G Simpson, durante la década de los 70 un creciente número de paleontólogos decidieron apuntar sus esfuerzos hacía el estudio de los procesos evolutivos, labor que hasta ese entonces era desarrollada por genetistas y ecólogos (Mayr 1940; Dobzhansky 1950; Fischer 1960). Esto implicaría el desarrollo de una amplia diversidad de líneas de investigación en la que sería llamada la revolución paleobiológica (Turner 2011). Autores como N. Eldredge, S.J. Gould, D. Raup, J. Sepkoski, S. Stanley y E.Vrba, entre otros, bajo la premisa que el estudio de los fósiles puede aportar invaluable información sobre los procesos evolutivos, realizarían importantes avances hacía la generación de nuevas hipótesis y teorías evolutivas a partir de información paleontológica (Raup et al. 1973; Stanley 1975; Gould & Eldredge 1977; Gould et al. 1977; Vrba 1980; Gould & Vrba 1982; Raup & Sepkoski 1986; Vrba & Gould 1986; Vrba 1992; Sepkoski Jr 1993, 1996). Este sería el comienzo de lo que se denominaría la escala macroevolutiva, la cual se define como el estudio de los cambios y procesos evolutivos por encima del nivel de especie (Stanley 1975; Cracraft 1985b). Uno de los procesos que más ha intrigado a los investigadores es el incremento en la biodiversidad y por qué ciertos taxones presentan una mayor riqueza de especies con respecto a otros (Gaston 2000).

Considerando lo anterior, el estudio de la diversificación como el balance de especiación y extinción es fundamental para comprender la dinámica de cómo los grupos han evolucionado hasta nuestros días (Mittelbach et al. 2007; Morlon 2014). A lo largo de la historia de la tierra factores abióticos como cambios climáticos y procesos geológicos han provocado la extinción de muchas especies e incluso de taxones completos (Sepkoski Jr 1996; Arens & West 2008; Benton 2009), así como también la posterior radiación adaptativa de otros (Cooper & Fortey 1998). Esto hace de los factores abióticos importantes condicionantes del componente biótico y por consiguiente principales promotores de cambio evolutivo a gran escala (Vrba 1993; Vrba 2004; Benton 2009; Condamine et al. 2013a).

En la visión clásica las primeras representaciones filogenéticas eran una mera esquematización de las relaciones de parentesco entre los grupos naturales y eran una importante herramienta en la clasificación taxonómica (Turner 2011). Sin embargo, en la actualidad con el desarrollo de técnicas moleculares y computacionales más eficientes, las aproximaciones filogenéticas son cada vez más robustas y confiables

permitiendo un mejor conocimiento de los patrones evolutivos de las especies (Glor 2010; FitzJohn 2012; Drummond et al. 2012; Pennell & Harmon 2013; Morlon 2014). El creciente surgimiento de filogenias con un mayor contenido de clados relacionados entre sí ha ofrecido una fuente de información a los estudios macroevolutivos para consolidar diversos métodos comparativos que integran las filogenias con gran cantidad de datos biológicos y paleobiológicos (Garland et al. 1993; Alroy 1996; Mooers et al. 1999; Losos & Glor 2003; Garland et al. 2005; Cardillo 2011; Eastman et al. 2011; Jetz et al. 2012; Pennell & Harmon 2013; Cantalapiedra et al. 2013; Cantalapiedra et al. 2014; Morlon 2014). Asimismo, debido a que su topología tiene implícita la señal del pasado, esto ha permitido ampliar el horizonte explicativo de la influencia de los procesos históricos, algunos de ellos bien conocidos, en la diversificación de los diversos grupos taxonómicos (Hawkins et al. 2006; Hernández Fernández & Vrba 2005b; Finarelli & Badgley 2010; Hoffmann & Sgrò 2011; Cantalapiedra et al. 2011; Kozak & Wiens 2012; Toussaint et al. 2012; Davies & Buckley 2011; Condamine et al. 2013b; Near et al. 2013; Batalha-Filho et al. 2014).

En este contexto y desde una perspectiva paleobiológica, la inclusión de información fósil provee un marco conceptual importante para el estudio de diversas hipótesis macroevolutivas a través de los patrones observados e inferidos en las filogenias (Gavrilets & Losos 2009; Pennell & Harmon 2013). Preguntas acerca de cómo han cambiado la disparidad y la diversidad a través del tiempo; cuáles han sido los principales agentes históricos (abióticos y bióticos) que han influido en estos patrones; cuáles han sido los roles de la dispersión y la vicarianza en los patrones biogeográficos de la diversidad, así como el papel de las innovaciones evolutivas en la diversificación, son preguntas que son abordadas con renovado entusiasmo gracias a la creciente información paleontológica y paleoecológica (Barnosky 2001; Sanmartín & Ronquist 2004; Noonan & Chippindale 2006; Hernández Fernández et al. 2007, 2015; Tiffney 2008; Davies et al. 2011; Pyron & Burbrink 2012; Tingley & Dubey 2012; Álvarez-Sierra et al. 2013; Gómez Cano et al. 2013, 2014; Benson et al. 2014; Domingo et al. 2014; Mitchell & Makovicky 2014; Pelegrin et al. 2014b; Morales et al. 2015). Los trabajos con información del registro fósil han resultado ser complementarios a las filogenias moleculares, aportando una evidencia histórica directa que permite la datación de las mismas mediante la asignación de un tiempo mínimo de ocurrencia de los eventos de cladogénesis (Hernández Fernández & Vrba

2005b; Pennell & Harmon 2013; Mayr 2014). Asimismo, han logrado generar intervalos temporales para el desarrollo de determinados caracteres, algunos de ellos claves en los procesos de radiación adaptativa (Cantalapiedra et al. 2013; Pennell & Harmon 2013; Pelegrin et al. 2014b). Finalmente, los fósiles constituyen evidencias directas de presencia en un área geográfica determinada, que en muchos casos puede ser distinta a la actual (Mayr 2009). Este último aspecto es fundamental para el análisis espacio-temporal de la diversidad y en la reconstrucción paleobiogeográfica debido a que se pueden inferir las condiciones en las cuales habrían evolucionado los organismos en momentos tempranos de su historia (Maguire & Stigall 2008; Sanisidro & Cantalapiedra 2010; Loewen et al. 2013). En este sentido, con la integración de la biogeografía histórica, las distribuciones de los organismos en un contexto filogenético han aportado información acerca de la importancia de los procesos de especiación por dispersión o vicarianza en la diversificación de los linajes (Sanmartín & Ronquist 2004; Condamine et al. 2013b). Lo anterior ha sido fundamental para la generación de nuevas aproximaciones metodológicas integradas en análisis como Lagrange (Yu et al. 2015) o BioGeoBears (Matzke 2014), las cuales logran construir un modelo macroevolutivo de la dinámica espacio-temporal basado en datos filogenéticos, paleontológicos, geológicos y biogeográficos (Ree & Smith 2008; Alfaro et al. 2015; Mendoza et al. 2015).

En el caso de las aves, la información del registro fósil ha presentado un destacado incremento en las últimas décadas, y ha ofrecido la oportunidad de calibrar con mayor confianza las hipótesis filogenéticas más recientes (Ericson et al. 2006; Jetz et al. 2012; Jarvis et al. 2014). Sin embargo, muchas de las filogenias moleculares no consideran un número de fósiles adecuado o en muchos casos sus especímenes de referencia se corresponden con representantes de *stem groups* en lugar de *crown groups* lo que introduce un importante sesgo a las dataciones filogenéticas generando una sobre o subestimación del periodo de origen de los grupos (Ksepka et al. 2014; Mayr 2014). Aunque a diferencia de los mamíferos las aves no presentan un registro tan amplio (Alroy 2014), análisis como el de Ksepka y Boyd (2012) evidencian que este sí puede aportar evidencias históricas para la gran mayoría de los grupos presentes en la actualidad y muchos de sus parientes más próximos (Ksepka & Boyd 2012; Smith 2015).

La distribución geográfica de las especies actuales es el producto de su historia natural y esta en sí misma es una valiosa fuente de información para el estudio de los procesos evolutivos que han llevado a consolidarla (Vrba 1995; Cardillo 1999; Dynesius & Jansson 2000; Barnosky et al. 2003; Hawkins et al. 2003a; Gaston et al. 2004; Hawkins & Diniz-Filho 2004; Porzecanski & Cracraft 2005; Davies et al. 2011; Hernández Fernández 2001; Hernández Fernández & Vrba 2005a, 2005c, 2005d; Moreno Bofarull et al. 2008; Hawkins et al. 2012; Springer et al. 2012; Pigot & Tobias 2013; Cantalapiedra et al. 2014). En el caso específico de las aves, el destacado conocimiento de sus distribuciones y patrones migratorios (Del Hoyo et al. 1992-2002; Berthold et al. 2003), así como el creciente estudio de sus relaciones filogenéticas esta permitiendo el progresivo desarrollo de nuevas aproximaciones teóricas para establecer un marco espacial y temporal de cómo estos patrones se han configurado históricamente en las aves (Cracraft 1985a; Berthold 1999; Webb & Gaston 2000; Jetz & Rahbek 2002; Tris et al. 2004; Hawkins et al. 2006; Hawkins et al. 2007; Jetz et al. 2008; Şekercioğlu et al. 2008; Dalsgaard et al. 2011; Dalby et al. 2014; Kennedy et al. 2014; Rolland et al. 2014; Smith et al. 2014). Sin embargo, a diferencia de los trabajos con mamíferos, la inclusión de información fósil en este tipo de trabajos es aún escasa (García-R et al. 2014; Smith & Clarke 2014; Fuchs et al. 2015).

Desde una perspectiva ecológica, los ecosistemas están estructurados por un componente abiótico que a su vez condiciona el biótico (Brown 1995; Ricklefs 2008). De esta manera, las especies que componen la comunidad evolucionan con unas características particulares respondiendo así a las condiciones climáticas y ambientales del ecosistema (Newton 2003). Esto puede generar que aunque históricamente dos linajes sean distintos, su morfología y fisiología puedan ser similares (van Tuinen et al. 2001).

Existe un estrecho vinculo entre la evolución de los organismos y su contexto ambiental (Darwin 1859), así como regiones terrestres de mayor biodiversidad (Gaston 2000), y son muchas las hipótesis evolutivas que intentan explicar los patrones de distribución geográfica a la luz de la diversificación y distribución que muestran las especies (Mittelbach et al. 2007). Partiendo de la premisa de igual diversificación, autores pioneros como Wallace (1878) hasta modernos como Wiens & Donoghue (2004) o Fine & Ree (2006), proponen que la abundancia de las especies

en los ambientes tropicales se debe a la antigüedad de estos, lo cual se correspondería con la antigüedad de muchos de sus linajes. Asimismo, Latham & Ricklefs (1993), Farrell & Mitter (1993), Hawkins et al. (2006) postulan que las dispersiones fuera de los trópicos hacia las regiones templadas serían más recientes y limitadas a algunos grupos. Por el contrario, otros investigadores proponen diferencias sustanciales entre las tasas de diversificación, siendo más altas en los ecosistemas tropicales respecto a los templados. De acuerdo con diversas propuestas, estas diferencias serían promovidas principalmente por factores como: 1) la deriva genética y procesos selectivos de pequeñas poblaciones que aceleran las tasas de especiación (Fedorov 1966; Schneider et al. 1999); 2) las variaciones climáticas que promueven la especiación en bajas latitudes (Haffer 1969; Vrba 1985,1995; Dynesius & Jansson 2000); 3) la alta probabilidad para la especiación simpátrica (Gentry 1989) y parapátrica (Moritz et al. 2000); 4) el mayor área de los ambientes tropicales provee más oportunidades para el aislamiento geográfico (Wright 1983; Rosenzweig 1995); 5) un rango fisiológico de tolerancia estrecho reduciría la dispersión hacia ambientes desfavorables (Janzen 1967; Ghalambor et al. 2006); 6) las altas temperaturas promueven el incremento de la velocidad en el cambio evolutivo (Allen et al. 2006); 7) las fuertes interacciones bióticas llevan hacia una mayor especialización y un incremento de la especiación (Dobzhansky 1950; Paine 1966; Schemske 2002); 8) la estabilidad climática de los ambientes tropicales reduce las tasas de extinción (Darwin 1859; Wallace 1878; Fischer 1960); 9) las áreas tropicales grandes promueven poblaciones grandes, amplios rangos de distribución y de esta manera bajas tasas de extinción (Rosenzweig 1995). Finalmente, la inclusión de una perspectiva filogenética en las diversas hipótesis evolutivas sería fundamental en el desarrollo de lo que se ha denominado el principio de la conservación del nicho (Wiens 2004; Losos 2008) o, lo que es lo mismo, la retención filogenética de características ecológicas ancestrales (Wiens 2004; Wiens et al. 2010).

Considerando lo anterior, podríamos afirmar que los patrones macroevolutivos son un entramado complejo de factores abióticos y bióticos actuando juntos en el marco de la contingencia evolutiva de cada clado (Benton 2009). En este contexto, una de las interpretaciones más integradoras fue la realizada por Vrba (1980, 1987). Esta establece un rol primario de los agentes abióticos (procesos geológicos y cambios climáticos) como principales promotores de especiación y extinción, modulado por los distintos niveles de especialización a unas condiciones

ambientales específicas, determinadas por la estructura y recursos de un bioma particular. Con lo cual, aquellas especies que son "especialistas" en el bioma de distribución que habitan, son mas susceptibles a altas tasas de especiación por eventos de vicarianza a partir de cambios ambientales o geológicos drásticos que puedan suceder en sus zonas de distribución. Por el contrario las "generalistas" ocupando varios biomas y adaptadas a una variedad amplia de condiciones fisiográficas, tendrán menores tasas de especiación y extinción (Vrba 1980; Vrba 1987, 1992, 1999). De esta manera, según la hipótesis de Vrba, biomas tropicales como las selvas lluviosas, con un régimen climático extremo de lluvia y temperatura, pero con una estabilidad anual, presentarían altas tasas de diversificación de especies debido a los constantes y alternantes procesos de expansión y contracción promovidos por cambios climáticos a lo largo de su historia (Vrba 1993). De esta manera, diversos aspectos abordados en las hipótesis expuestas anteriormente como: el tiempo, siendo uno de los biomas más antiguos y con mayor área (Fine & Ree 2006); su alta productividad primaria (Hawkins et al. 2003b); el desarrollo de adaptaciones morfofisiológicas en relación a la temperatura que serían posteriores limitaciones en la adaptación a nuevos ambientes (Ghalambor et al. 2006; Araújo et al. 2013); la tendencia filogenética hacia la conservación de diversas características ecológicas (Wiens & Graham 2005); así como otros aspectos relacionados con interacciones bióticas (Graham et al. 2006) estarían inmersos en este contexto explicativo. Esta visión macroevolutiva vincularía al bioma y su dinámica espacio-temporal en una visión integradora de las diversas hipótesis evolutivas expuestas y nos permitiría construir un marco teórico holístico para la comprensión de los procesos y patrones macroevolutivos de los organismos. En nuestro caso de las aves.

3. El concepto de Bioma en ecología y evolución.

Factores abióticos como el clima, la topografía y el suelo tienen un efecto en los caracteres presentes en las plantas y los animales, y por ende en la estructura de los ecosistemas (Ricklefs 2008). Aunque por cuestiones filogenéticas, espaciales e históricas dos localidades no compartan las mismas especies, se pueden clasificar las comunidades y los ecosistemas en categorías basadas en las condiciones climáticas y vegetales dominantes. Estas categorías reciben el nombre de biomas (Walter 1970; Whittaker 1975). Los ecosistemas pertenecientes a un mismo bioma compartirán una

vegetación similar, así como un funcionamiento energético similar. Lo anterior hace que los biomas sean puntos de referencia para el estudio de muchos procesos a escala global (Hernández Fernández 2001; Hernández Fernández & Vrba 2005a; Moreno Bofarull et al. 2008; Ricklefs 2008; Cantalapiedra et al. 2011; Jetz & Fine 2012; Gómez Cano et al. 2013).

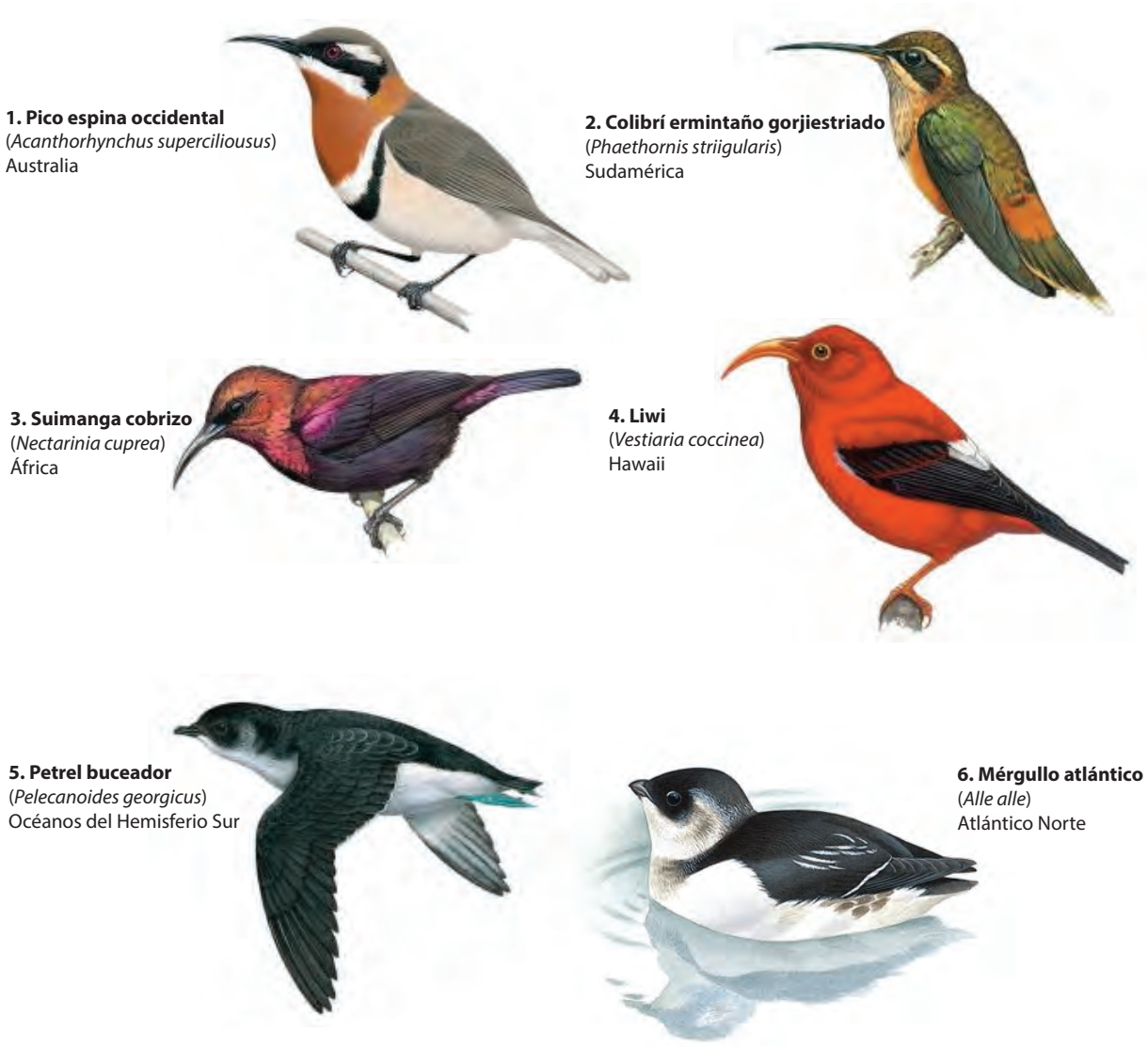


Figura 3. Convergencia morfológica en linajes de aves no emparentados ocupando hábitats y ambientes similares (arriba) aves nectarívoras de los bosques tropicales; (abajo) aves adaptadas a ambientes marinos.

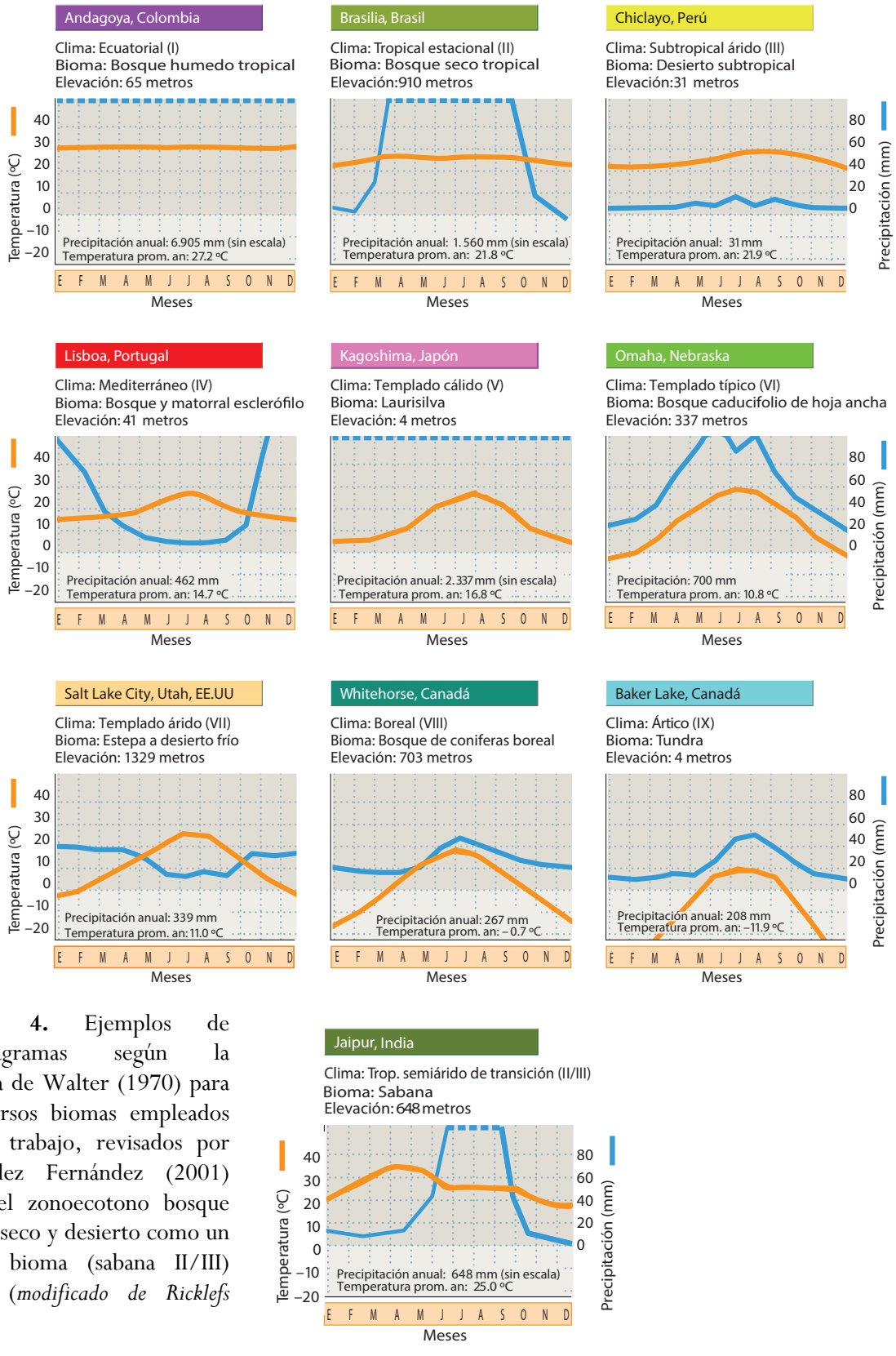


Figura 4. Ejemplos de climodiagramas según la tipología de Walter (1970) para los diversos biomas empleados en este trabajo, revisados por Hernández Fernández (2001) añadió el zonoecotono bosque tropical seco y desierto como un décimo bioma (sabana II/III) (abajo) (*modificado de Ricklefs 2008*).

El bioma como escala de trabajo en macroecología y macroevolución cobra importancia debido a que integra una identidad histórica en términos de procesos tectónicos y climáticos que los han configurado (Pennington et al. 2004; Ricklefs 2008; Jetz & Fine 2012). Pese a su distancia geográfica, los ecosistemas de bosques lluviosos tropicales son similares en la Amazonía de Sudamérica, las selvas del Congo en África ecuatorial o las junglas de Indonesia (Plana 2004; Wong 2011; Jaramillo & Cárdenas 2013). A parte del régimen climático como principal determinante la vegetación en estos biomas, también existen importantes similitudes en su productividad, reciclaje de nutrientes y estructura de las comunidades animales, evidenciándose en estas últimas destacados procesos de convergencia (Ricklefs 2008)(Fig.3). Complementando a lo anterior, los biomas al establecerse como arenas evolutivas adquieren asimismo sus propias dinámicas evolutivas en términos de especiación y extinción en relación a sus procesos históricos (Woodward et al. 2004; Jetz & Fine 2012; Donoghue & Edwards 2014; Guerrero et al. 2014).

Diversos sistemas de clasificación han sido desarrollados para los biomas, sin embargo uno de los más aceptados y utilizados ha sido el desarrollado por Walter (1970). Este sistema originalmente en nueve divisiones, esta basado en los ciclos anuales de temperatura y precipitación (Fig.4). Los valores de temperatura y precipitación son usados para definir las zonas climáticas, las cuales se corresponden con las condiciones de humedad y estrés térmico fundamental para el desarrollo de las comunidades vegetales (Walter 1970). De esta manera, por ejemplo, el bioma de estepa esta definido por una zona climática continental (desiertos fríos) que implica un régimen de aridez con veranos cálidos o templados e inviernos fríos, condicionando una vegetación tipo pradera de gramíneas. La tipología de Walter (1970) es sencilla y tiene fácil correspondencia con otros sistemas desarrollados (Holdridge 1967; Whittaker 1975).

Asimismo, esta ha sido modificada y actualizada por Hernández Fernández (2001) con un décimo bioma (Sabana – II/III), originalmente ecotono entre el bosque seco tropical y el desierto, debido a la complejidad faunística e importancia que ha mostrado en estudios ecológicos y paleoecológicos (Hernández Fernández 2001; Jacobs 2004; Bird et al. 2005; Hernández Fernández et al. 2007; Bouchenak-Khelladi & Hodkinson 2011).

En tiempos recientes diversos autores han consolidado el bioma como importante escala de estudio en diversos trabajos que lo vinculan al análisis de la conservación de nicho (Crisp et al. 2009; Donoghue & Edwards 2014; Jara-Arancio et al. 2014), al estudio de procesos macroevolutivos en mamíferos y aves (Hernández Fernández & Vrba 2005a; Moreno Bofarull et al. 2008; Cantalapiedra et al. 2011; Gómez Cano et al. 2013; Pelegrin et al. 2015), así como a diversos trabajos que integran este concepto en estudios filogenéticos, macroecológicos y paleoclimáticos (Hernández Fernández et al. 2007; Jetz & Fine 2012; Guerrero et al. 2013; Cantalapiedra et al. 2014; Pelegrin et al. 2014a).

4. Objetivos

Esta investigación doctoral se encuentra enmarcada en un enfoque macroecológico y macroevolutivo, que mediante el análisis filogenético de la biogeografía y la paleobiogeografía, pretende generar una visión integradora para comprender los patrones de radiación, dispersión y adaptación de las aves no paseriformes. Para lo cual, esta tesis pretende analizar la relación histórica entre los cambios climáticos y geológicos globales acaecidos desde el Cretácico Superior y durante el Cenozoico en la configuración de estos patrones. De acuerdo con lo anteriormente expuesto, este proyecto de tesis doctoral se encuentra planteado bajo tres objetivos principales que se detallan a continuación:

1. Analizar la influencia de los cambios climáticos globales en los procesos de cladogénesis en las aves no paseriformes

A lo largo del tiempo, cambios y variaciones ambientales han logrado configurar zonas donde se propician los eventos de especiación, diversificación y extinción. Esto parece estar relacionado con las características ecológicas de los linajes afectados, y en particular con su grado de especialización ecológica. Por ello, tras realizar una exhaustiva caracterización ecológica de todas las especies actuales de aves no paseriformes, en el capitulo 2 de este trabajo se aborda la relación entre la especiación ecológica, los ambientes ocupados y la diversidad biológica en los diferentes grupos de aves no paseriformes. De esta manera empleando técnicas de análisis estadístico de amplia robustez hemos contrastado las hipótesis de E.S. Vrba acerca de la influencia de los cambios climáticos en los eventos de diversificación cladogenética. Asimismo,

estos análisis nos permitieron analizar la influencia de la dieta o la capacidad de migrar a larga distancia en los patrones de especialización ecológica.

2. Analizar los patrones de dispersión paleobiogeográfica de las aves modernas (Neornithes)

Se ha realizado una amplia revisión del registro fósil de Neornithes, incluyendo la recopilación de información filogenética de diversos taxones extintos. Además, se ha logrado combinar esta información con datos procedentes de distribuciones de especies actuales, así como de las diferentes configuraciones climáticas y tectónicas de la tierra en los últimos 90 millones de años. Así, se pretende presentar una aproximación macroevolutiva mediante la reconstrucción filogenética de caracteres ancestrales que permita generar nuevas hipótesis sobre el origen geográfico y la diversificación de los diferentes linajes de aves modernas desde su aparición en el Cretácico Superior. Igualmente, se explora qué escenarios evolutivos resultarían viables para explicar los diferentes eventos de dispersión a lo largo del tiempo geológico. La integración de toda la información paleo- y neontológica permite abordar un estudio exhaustivo de la evolución geográfica de este grupo de vertebrados, proponiendo un nuevo escenario evolutivo a gran escala.

3. Analizar las vías de adaptación de dos diferentes linajes de aves a distintos regímenes climáticos

Exploramos cómo diferentes grupos de aves han logrado adaptarse a climas específicos así como a los nuevos climas que emergieron en diferentes periodos temporales. Para este fin se han elegido dos grupos de los que tenemos un conocimiento filogenético, ecológico y geográfico amplio: Galliformes y Falconiformes. Mediante la aplicación de nuevas técnicas de análisis comparativo basadas en programas de análisis estadístico en un marco filogenético, se determinan las posibles relaciones entre los diversos factores ecológicos y los procesos históricos que han permitido la ocupación de los diferentes biomas terrestres durante la evolución de los dos linajes de Aves. Asimismo, el análisis desde una perspectiva filogenética de los patrones obtenidos en los dos grupos de aves permiten evaluar la conservación de nicho, aplicada al contexto de especialización biómica en una escala temporal amplia. Esto permite el contraste con los cambios ambientales inferidos a partir de evidencias paleoambientales derivadas del registro geológico, datos

geoquímicos, paleobotánicos y de cambios faunísticos.

Acometer las tareas derivadas de estos objetivos nos permitirá profundizar en el conocimiento de procesos evolutivos observados a diferentes escalas, los cuales han dado forma a las faunas modernas. De esta manera, se podrán sugerir nuevas hipótesis evolutivas sobre las posibles condiciones ambientales responsables del origen, diversificación y extinción de los grupos taxonómicos estudiados.

5. LITERATURA CITADA

Alfaro JWL, Boubli JP, Paim FP, Ribas CC, da Silva MNF, Messias MR, Röhe F, Mercês MP, Júnior JSS, Silva CR (2015) Biogeography of squirrel monkeys (genus *Saimiri*): South-central Amazon origin and rapid pan-Amazonian diversification of a lowland primate. *Mol Phylogenet Evol* 82:436-454

Allen AP, Gillooly JF, Savage VM, Brown JH (2006) Kinetic effects of temperature on rates of genetic divergence and speciation. *Proc Natl Acad Sci USA*103 (24):9130-9135

Alonso PD, Milner AC, Ketcham RA, Cookson MJ, Rowe TB (2004) The avian nature of the brain and inner ear of *Archaeopteryx*. *Nature* 430 (7000):666-669

Alroy J (1996) Constant extinction, constrained diversification, and uncoordinated stasis in North American mammals. *Palaeogeogr Palaeoclimatol Palaeoecol* 127:285-311

Alroy J (2014) *Paleobiology Database*. Macquarie University. http://paleodb.org. 2013

Álvarez-Sierra MÁ, García-Paredes I, Hernández-Ballarín V, Hoek Ostende LWvd, Hordijk K, López-Guerrero P, Meulen AJvd, Oliver A, Pélaez-Campomanes P (2013) Models of historical biogeography and continental biochronology. *Spanish Journal of Palaeontology* 28 (2):129-138

Araújo MB, Ferri-Yáñez F, Bozinovic F, Marquet PA, Valladares F, Chown SL (2013) Heat freezes niche evolution. *Ecol Lett* 16 (9):1206-1219. doi:10.1111/ele.12155

Arens NC, West ID (2008) Press-pulse: a general theory of mass extinction? *Paleobiology* 34 (4):456-471. doi:10.1666/07034.1

Audubon JJ (1843) *The birds of America*, vol 6. JJ Audubon

Baker AJ, Haddrath O, McPherson JD, Cloutier A (2014) Genomic Support for a Moa-Tinamou Clade and Adaptive Morphological Convergence in Flightless Ratites. *Mol Biol Evol.* 31(7):1686-1696

Barker FK, Barrowclough GF, Groth JG (2002) A phylogenetic hypothesis for passerine birds: taxonomic and biogeographic implications of an analysis of nuclear DNA sequence data. *Proc R Soc Lond B* 269 (1488):295-308

Barker FK, Cibois A, Schikler P, Feinstein J, Cracraft J (2004) Phylogeny and diversification of the largest avian radiation. *Proc Natl Acad Sci USA* 101 (30):11040-11045.

Barnosky A (2001) Distinguishing the effects of the red queen and court jester on Miocene mammal evolution in the Northern Rocky Mountains. *J Vertebr Paleontol* 21:172 - 185

Barnosky AD, Hadly EA, Bell CJ (2003) Mammalian response to global warming on varied temporal scales. *J Mammal* 84 (2):354-368

Batalha-Filho H, Pessoa RO, Fabre P-H, Fjeldså J, Irestedt M, Ericson PG, Silveira LF, Miyaki CY (2014) Phylogeny and historical biogeography of gnateaters (Passeriformes, Conopophagidae) in the South America forests. *Mol Phylogenet Evol* 79:422-432

Bell A, Everhart MJ (2009) A new specimen of *Parahesperornis* (Aves: Hesperornithiformes) from the Smoky Hill Chalk (Early Campanian) of western Kansas. *Trans Kans Acad Sci* 112 (1/2):7-14

Benson RBJ, Campione NE, Carrano MT, Mannion PD, Sullivan C, Upchurch P, Evans DC (2014) Rates of dinosaur body mass evolution indicate 170 million years of sustained ecological innovation on the avian stem lineage. *PLoS biol* 12 (5):e1001853

Benton J (2009) The Red Queen and the Court Jester: species diversity and the role of biotic and abiotic factors through time. *Science* 323:728 - 732

Berthold P (1999) A comprehensive theory for the evolution, control and adaptability of avian migration. *Ostrich* 70 (1):1-11

Berthold P, Gwinner E, Sonnenshein E (2003) *Avian Migration*. Springer, Berlin, New York

Bird MI, Taylor D, Hunt C (2005) Palaeoenvironments of insular Southeast Asia during the Last Glacial Period: a savanna corridor in Sundaland? *Quat Sci Rev* 24 (20):2228-2242

Birkhead TR, Charmantier I (2001) History of Ornithology. In: *Enclycopedia of Life Sciences*. John Wiley & Sons, Ltd. Chichester

Block WM, Brennan LA (1993) The habitat concept in ornithology. In: *Current ornithology*. Springer, pp 35-91

Bouchenak-Khelladi Y, Hodkinson T (2011) Savanna biome evolution, climate change and the ecological expansion of C4 grasses.In: Hodkinson TR, Jones MB, Wldren S, et al. *Climate Change, Ecology and Systematics.* Cambridge University Press:156

Braun EL, Kimball RT (2002) Examining basal avian divergences with mitochondrial sequences: model complexity, taxon sampling, and sequence length. *Syst Biol*:614-625

Brown JH (1995) *Macroecology*. University of Chicago Press

Brusatte SL, Lloyd GT, Wang SC, Norell MA (2014) Gradual assembly of avian body plan culminated in rapid rates of evolution across the dinosaur-bird transition. *Curr Biol* 24 (20):2386-2392

Burnham DA (2007) *Archaeopteryx*: a re-evaluation suggesting an arboreal habitat and an intermediate stage in trees down origin of flight. *Neues Jahrbuch für Geologie und Paläontologie-Abhandlungen* 245 (1):33-44

Callaway E (2014) Rival species recast significance of first bird. *Nature* 516 (7529):18

Cantalapiedra JL, FitzJohn RG, Kuhn TS, Hernández Fernández M, DeMiguel D, Azanza B, Morales J, Mooers AØ (2013) Dietary innovations spurred the diversification of ruminants during the Caenozoic. *Proc R Soc Lond B* 281 (1776):20132746

Cantalapiedra JL, Hernández Fernández M, Morales J (2011) Biomic specialization and speciation rates in ruminants (Cetartiodactyla, Mammalia): a test of the resourse-use hypothesis at global scale. *PLoS ONE* 6 (12): e28749

Cantalapiedra JL, Hernández Fernández M, Morales J (2014) The biogeographic history of ruminant faunas determines the phylogenetic structure of their assemblages at different scales. *Ecography* 36:1-9

Cardillo M (1999) Latitude and rates of diversification in birds and butterflies. *Proc R Soc Lond B* 266 (1425):1221-1225.

Cardillo M (2011) Phylogenetic structure of mammal assemblages at large geographical scales: linking phylogenetic community ecology with macroecology. *Philos Trans R Soc B* 366:2545-2553

Cardillo M, Orme CDL, Owens IPF (2005) Testing for latitudinal bias in diversification rates: an example using New Wold Birds. *Ecology* 86 (9):2278-2287

Chatterjee S, Templin RJ (2003) The flight of *Archaeopteryx*. *Naturwissenschaften* 90 (1):27-32

Chatterjee S, Templin RJ (2007) Biplane wing planform and flight performance of the feathered dinosaur *Microraptor gui*. *Proc Natl Acad Sci USA* 104 (5):1576-1580

Chesser RT, Zink RM (1994) Modes of speciation in birds: A test of Lynch's method. *Evolution* 48 (2):490-497

Chiappe LM (1995) The phylogenetic position of the Cretaceous birds of Argentina: Enantiornithes and *Patagopteryx deferrariisi*. *Cour Forschungsinst Senckenb* 181:55-63

Chiappe LM (2002) Basal bird phylogeny: Problems and solutions. In: Chiappe LM, Witmer LM (eds) *Mesozoic Birds. Above the heads of the Dinosaurs*. University of California Press, Berkeley, pp 448-472

Chiappe LM (2007) *Glorified dinosaurs: the early evolution of birds*.John Wiley & Sons: Hoboken, NJ, pp 192

Chiappe LM, Dyke GJ (2002) The Mesozoic radiation of birds. *Annu Rev Ecol Syst*:91-124

Chiappe LM, Dyke GJ (2006) The early evolutionary history of birds. *J Paleont South Korea* 22 (1):133-151

Chiappe LM, Ji S-A, Ji Q, Norell MA (1999) Anatomy and systematics of the Confuciusornithidae (Theropoda, Aves) from the late Mesozoic of northeastern China. *Bull Am Mus Nat His*; no. 242.

Chiappe LM, Walker CA (2002) Skeletal morphology and systematics of the Cretaceous Euenantiornithes (Ornithothoraces: Enantiornithes).In: Chiappe LM, Witmer LM (eds). *Mesozoic birds: above the heads of dinosaurs*:240-267

Chiappe LM, Witmer LM (2002) *Mesozoic birds: above the heads of dinosaurs.* University of California Press, Berkeley

Christiansen P, Bonde N (2000) Axial and appendicular pneumaticity in *Archaeopteryx*. *Proc R Soc Lond B* 267 (1461):2501-2505

Clarke J (2013) Feathers before flight. *Science* 340 (6133):690-692

Clarke JA (2004) Morphology, phylogenetic taxonomy, and systematics of *Ichthyornis* and *Apatornis* (Avialae: Ornithurae). *Bull Am Mus Nat Hist*:1-179

Clarke JA, Tambussi CP, Noriega JI, Erickson GM, Ketcham (2005) Definitive fossil evidence for the extant avian radiation in the Cretaceous. *Nature* 433:305-308

Condamine FL, Rolland J, Morlon H (2013a) Macroevolutionary perspectives to environmental change. *Ecol Lett* 16 (s1):72-85

Condamine FL, Sperling FAH, Kergoat GJ (2013b) Global biogeographical pattern of swallowtail diversification demostrates alternative colonization routes in the Northern and Southern hemispheres. *J Biogeogr* 40:9-23

Cooper A, Fortey R (1998) Evolutionary explosions and the phylogenetic fuse. *Trends Ecol Evol* 13 (4):151-156

Cooper A, Penny D (1997) Mass Survival of Birds Across the Cretaceous- Tertiary Boundary: Molecular Evidence. *Science* 275 (5303):1109-1113.

Cracraft J (1985a) Historical Biogeography and Patterns of differentiation within the South American avifauna: Areas of Endemism. American Ornithologist Union, *Ornithology Monografts* 36:49-84

Cracraft J (1985b) Species Selection, Macroevolutionary Analysis, and the "Hierarchical Theory" of Evolution. *Syst Zool* 34 (2):222-229

Cracraft J (1986) The origin and early diversification of birds. *Paleobiology* 12 (4):383-399

Cracraft J (2001) Avian evolution, Gondwana biogeography and the Cretaceous Tertiary mass extinction event. *Proc R Soc Lond B* 268:459-469

Crisp M, Arroyo MT, Cook LG, Gandolfo MA, Jordan GJ, McGlone MS, Weston P, Westoby M, Wilf P, Linder HP (2009) Phylogenetic biome conservatism on global scale. *Nature* 458:754-756

Cronk Q, Ojeda I (2008) Bird-pollinated flowers in an evolutionary and molecular context. *J Exp Bot* 59 (4):715-727

Dalby L, McGill BJ, Fox AD, Svenning JC (2014) Seasonality drives global-scale diversity patterns in waterfowl (Anseriformes) via temporal niche exploitation. *Glob Ecol Biogeogr* 23 (5):550-562

Dalsätt J (2012) *Fossil birds: Contributions to the understanding of avian evolution*. Ph.D Thesis. Stockholm University, Faculty of Science, Department of Geological Sciences.

Dalsgaard B, Magård E, Fjeldså J, González AMM, Rahbek C, Olesen JM, Ollerton J, Alarcón R, Araujo AC, Cotton PA (2011) Specialization in plant-hummingbird networks is associated with species richness, contemporary precipitation and quaternary climate-change velocity. *PLoS One* 6 (10):e25891

Darwin C (1859) *On the origins of species by means of natural selection*. London: Murray

Darwin C, Wallace A (1858) On the tendency of species to form varieties; and on the perpetuation of varieties and species by natural means of selection. *J Proc Linn Soc* 3:46 - 50

Davies TJ, Buckley LB (2011) Phylogenetic diversity as a window into the evolutionary and biogeographic histories of present-day richness gradients for mammals. *Philos Trans R Soc B* 366 (1576):2414-2425.

Davies TJ, Buckley LB, Grenyer R, Gittleman JL (2011) The influence of past and present climate on the biogeography of modern mammal diversity. *Philos Trans R Soc B* 366 (1577):2526-2535.

Del Hoyo J, Elliott A, Sargatal J (1992-2002) *Handbook of the Birds of the World*, vol 1-7. Lynx Edicions, Barcelona

Dobzhansky T (1950) Evolution in the tropics. *Am Sci* 38 (2):209-221

Domingo MS, Badgley C, Azanza B, DeMiguel D, Alberdi MT (2014) Diversification of mammals from the Miocene of Spain. *Paleobiology* 40(2):197-221.

Donoghue MJ, Edwards EJ (2014) Biome shifts and niche evolution in plants. *Ann Rev Ecol Evol Syst* 45:547-572

Drummond AJ, Suchard MA, Xie D, Rambaut A (2012) Bayesian phylogenetics with BEAUti and the BEAST 1.7. *Mol Biol Evol* 29 (8):1969-1973

Dynesius M, Jansson R (2000) Evolutionary consequences of changes in species' geographical distributions driven by Milankovitch climate oscillations. *Proc Natl Acad Sci USA* 97 (16):9115-9120

Eastman JM, Alfaro ME, Joyce P, Hipp AL, Harmon LJ (2011) A novel comparative method for identifying shifts in the rate of character evolution on trees. *Evolution* 65 (12):3578-3589

Egerton FN (2003) A History of the Ecological Sciences, Part 8. Frederick II of Hohenstaufen: Amateur Avian Ecologist and Behaviorist. *Bull Ecol Soc Am* 84 (1):40-44

Elzanowski A (2002) Archaeopterygidae (Upper Jurassic of Germany). In: Chiappe LM, Witmer LM (eds) *Mesozoic Birds. Above the heads of the Dinosaurs*. University of California Press, Berkeley:129-159

Eo SH, Bininda-Emonds ORP, Carroll JP (2009) A phylogenetic supertree of the fowls (Galloanserae, Aves). *Zool Scr* 38 (5):465-481

Erickson GM, Rauhut OWM, Zhou Z, Turner AH, Inouye BD, Hu D, Norell MA (2009) Was dinosaurian physiology inherited by birds? Reconciling slow growth in Archaeopteryx. *PLoS One* 4 (10):e7390

Ericson PGP (2008) Current perspectives on the evolution of birds. *Contrib Zool* 77 (2):109-116

Ericson PGP (2012) Evolution of terrestrial birds in three continents: Biogeography and parallel radiations. *J Biogeogr* 39:813-824

Ericson PGP, Anderson CL, Britton T, Elzanowski A, Johansson US, Källersjö M, Ohlson JI, Parsons TJ, Zuccon D, Mayr G (2006) Diversification of Neoaves: integration of molecular sequence data and fossils. *Biol Lett* 2 (4):543-547.

Ericson PGP, Christidis L, Cooper A, Irestedt M, Jackson J, Johansson U, Norman JA (2002) A Gondwanan origin of passerine birds supported by DNA sequences of the endemic New Zealand wrens. *Proc R Soc Lond B* 269:235-241

Fain MG, Houde P (2004) Parallel radiations in the primary clades of birds. *Evolution* 58 (11):2558-2573

Farrell BD, Mitter C (1993) Phylogenetic determinants of insect/plant community diversity. *Species diversity in ecological communities*:253-266

Fedorov AA (1966) The structure of the tropical rain forest and speciation in the humid tropics. *The Journal of Ecology*:1-11

Feduccia A (1999) *The origin and evolution of birds*. Yale University Press,

Feduccia A (2003) "Big bang" for tertiary birds? *Trends Ecol Evol* 18 (4):172-176

Feo TJ, Field DJ, Prum RO (2015) Barb geometry of asymmetrical feathers reveals a transitional morphology in the evolution of avian flight. *Proc R Soc Lond B* 282 (1803): 20142864; DOI: 10.1098/rspb.2014.2864.

Finarelli JA, Badgley C (2010) Diversity dynamics of Miocene mammals in relation to the history of tectonism and climate. *Proc R Soc Lond B* 277 (1694):2721-2726

Fine PVA, Ree RH (2006) Evidence for a time-integrated species-area effect on the latitudinal gradient in tree diversity. *Am Nat* 168 (6):796-804

Fischer AG (1960) Latitudinal variations in organic diversity. *Evolution* 14 (1):64-81

FitzJohn RG (2012) diversitree: comparative phylogenetic tests of diversification in R. *Meth Ecol Evol* 3 (6):1084-1092

Fjeldså J (1994) Geographical patterns of relict and young species of birds in Africa and South America and implications for conservation priorities. *Biodivers Conserv* 3:107-226

Foth C, Tischlinger H, Rauhut OWM (2014) New specimen of Archaeopteryx provides insights into the evolution of pennaceous feathers. *Nature* 511 (7507):79-82

Friesen VL, Anderson DJ (1997) Phylogeny and Evolution of the Sulidae (Aves: Pelecaniformes): A Test of Alternative Modes of Speciation. *Mol Phylogenet Evol* 7 (2):252-260

Fuchs J, I Ohlson J, GP Ericson P, Pasquet E (2006) Molecular phylogeny and biogeographic history of the piculets (Piciformes: Picumninae). *J Avian Biol* 37 (5):487-496

Fuchs J, Johnson JA, Mindell DP (2015) Rapid diversification of falcons (Aves: Falconidae) due to expansion of open habitats in the Late Miocene. *Mol Phylogenet Evol* 82:166-182

García-Moreno J (2004) Is there a universal mtDNA clock for birds? *J Avian Biol*:465-468

García-Moreno J, Sorenson MD, Mindell DP (2003) Congruent avian phylogenies inferred from mitochondrial and nuclear DNA sequences. *J Mol Evol* 57 (1):27-37

García-R JC, Gibb GC, Trewick SA (2014) Eocene diversification of crown group Rails (Aves: Gruiformes: Rallidae). *PLoS ONE* 9 (10):e109635

Garland T, Bennett AF, Rezende EL (2005) Phylogenetic approaches in comparative physiology. *J Exp Biol* 208 (16):3015-3035

Garland TJ, Dickerman AW, Janis CM, Jones JA (1993) Phylogenetic analysis of covariance by computer simulation. *Syst Biol* 42 (3):265-292

Gaston KJ (2000) Global patterns in biodiversity. *Nature* 405:220-227

Gaston KJ, Davies R, Gascoigne C, Williamson M (2004) The structure of global species–range size distributions: raptors y owls. *Glob Ecol Biogeogr* 14 (1):67-76

Gauthier J, Gall LF (2001) *New perspectives on the origin and early evolution of birds.* Peabody Museum of Natural History, Yale University, New Haven, Conn

Gavrilets S, Losos JB (2009) Adaptive radiation: contrasting theory with data. *Science* 323 (5915):732-737

Gentry A (1989) Speciation in tropical forests. *Tropical forests: Botanical dynamics, speciation and diversity*:113-134

Ghalambor CK, Huey RB, Martin PR, Tewksbury JJ, Wang G (2006) Are mountain passes higher in the tropics? Janzen's hypothesis revisited. *Integ Comp Biol* 46 (1):5-17

Gill FB (2007) *Ornithology*. 3 edn. WH Freeman, New York

Gingerich PD (1972) A new partial mandible of *Ichthyornis*. *Condor*:471-473

Gingerich PD (1973) Skull of *Hesperornis* and early evolution of birds. *Nature* 243:70-73

Glor RE (2010) Phylogenetic insights on adaptive radiation. *Ann Rev Ecol Evol Syst* 41:251-270

Godefroit P, Cau A, Dong-Yu H, Escuillié F, Wenhao W, Dyke G (2013) A Jurassic avialan dinosaur from China resolves the early phylogenetic history of birds. *Nature* 498 (7454):359-362

Göhlich UB, Chiappe LM (2006) A new carnivorous dinosaur from the Late Jurassic Solnhofen archipelago. *Nature* 440 (7082):329-332

Gómez Cano AR, Cantalapiedra JL, Mesa A, Moreno Bofarull A, Hernández Fernández M (2013) Global climate changes drive ecological specialization of mammal faunas: trends in rodent assemblages from the Iberian Plio-Pleistocene. *BMC Evol Biol* 13 (1):94

Gómez Cano AR, Cantalapiedra JL, Álvarez-Sierra MÁ, Hernández Fernández M (2014) A macroecological glance at the structure of late Miocene rodent assemblages from Southwest Europe. *Scientific reports* 4: 6567.

Gottschalk TK, Huettmann R, Ehlers M (2005) Thirty years of analysing and modelling avian habitat relationships using satellite imagery data: a review. *Int J Remote Sensing* 26:2631 - 2656

Gould SJ, Eldredge N (1977) Punctuated equilibria: the tempo and mode of evolution reconsidered. *Paleobiology*:115-151

Gould SJ, Raup DM, Sepkoski Jr JJ, Schopf TJ, Simberloff DS (1977) The shape of evolution: a comparison of real and random clades. *Paleobiology*:23-40

Gould SJ, Vrba E (1982) Exaptation: A Missing Term in the Science of Form. *Paleobiology* 8 (1):4-15

Graham CH, Moritz C, Williams SE (2006) Habitat history improves prediction of biodiversity in rainforest fauna. *Proc Natl Acad Sci USA* 103:632 - 636

Grant PR, Grant BR (2006) Evolution of character displacement in Darwin's finches. *Science* 313 (5784):224-226

Gregory JT (1952) The jaws of the Cretaceous toothed birds, *Ichthyornis* and *Hesperornis*. *Condor*:73-88

Gregory TR (2002) A bird′s eye view of c-value enigma: genome size, cell size, and metabolic rate in the class Aves. *Evolution* 56 (1):121-130

Griffiths CS, Barrowclough GF, Groth JG, Mertz L (2004) Phylogeny of the Falconidae (Aves): a comparison of the efficacy of morphological, mitochondrial, and nuclear data. *Mol Phylogenet Evol* 32:101-109

Groth JG, Barrowclough GF (1999) Basal divergences in birds and the phylogenetic utility of the nuclear RAG-1 gene. *Mol Phylogenet Evol* 12 (2):115-123

Guerrero PC, Rosas M, Arroyo MTK, Wiens JJ (2013) Evolutionary lag times and recent origin of the biota of an ancient desert (Atacama–Sechura). *Proc Natl Acad Sci USA* 110 (28):11469-11474

Hackett SJ, Kimball RT, Reddy S, Bowie RCK, Braun EL, Braun MJ, Chojnowski JL, Cox WA, Han K-L, Harshman J, Huddleston CJ, Marks BD, Miglia KJ, Moore WS, Sheldon FH, Steadman DW, Witt CC, Yuri T (2008) A Phylogenomic Study of Birds Reveals Their Evolutionary History. *Science* 320 (5884):1763-1768.

Haddrath O, Baker AJ (2001) Complete mitochondrial DNA geonome sequences of extinct birds: ratite phylogenetics and the vicariance biogeography hypothesis. *Proc R Soc Lond B* 268:939-945

Haffer J (1969) Speciation in Amazonian Forest Birds. *Science* 165 (3889):131-137

Haffer J (2008) The origin of modern ornithology in Europe. *Arch Nat Hist* 35 (1):76-87

Härlid A, Arnason U (1999) Analyses of mitochondrial DNA nest ratite birds within the Neognathae: supporting a neotenous origin of ratite morphological characters. *Proc R Soc Lond B* 266 (1416):305-309

Harshman J, Braun EL, Braun MJ, Huddleston CJ, Bowie RCK, Chojnowski JL, Hackett SJ, Han K-L, Kimball RT, Marks BD, Miglia KJ, Moore WS, Reddy S, Sheldon FH, Steadman DW, Steppan SJ, Witt CC, Yuri T (2008) Phylogenomic evidence for multiple losses of flight in ratite birds. *Proc Natl Acad Sci USA* 105 (36):13462-13467.

Hawkins B, Diniz-Filho JAF (2004) 'Latitude' and geographic patterns in species richness. *Ecography* 27 (2):268-272

Hawkins BA, Diniz-Filho JAF, Jaramillo CA, Soeller SA (2006) Post-Eocene climate change, niche conservatism, and the latitudinal diversity gradient of New World birds. *J Biogeogr* 33:770-780

Hawkins BA, Diniz-Filho JAF, Jaramillo CA, Soeller SA (2007) Climate, Niche Conservatism, and the Global Bird Diversity Gradient. *Am Nat* 170 (Supplement):S16-S27

Hawkins BA, Field R, Cornell RV, Currie DJ, Guégan J-F, Kaufman DM, Kerr JT, Mittelbach GG, Oberdorff T, O'Brien EM, Porter EE, Turner JRG (2003a) Energy, water, and broad-scale geographic patterns of species richness. *Ecology* 84 (12):3105-3117

Hawkins BA, McCain CM, Davies TJ, Buckley LB, Anacker BL, Cornell HV, Damschen EI, Grytnes J-A, Harrison S, Holt RD, Kraft NJB, Stephens PR (2012) Different evolutionary histories underlie congruent species richness gradients of birds and mammals. *J Biogeogr* 39:825-841

Hawkins BA, Porter EE, Felizola Diniz-Filho JAF (2003b) Productivity and history as predictors of the latitudinal diversity gradient of terrestrial birds. *Ecology* 84 (6):1608-1623

Heilmann G (1926) *The origin of birds.* HF & G. Witherby London,

Hernández Fernández M (2001) Bioclimatic discriminant capacity of terrestrial mammal faunas. *Glob Ecol Biogeogr* 10:189 - 204

Hernández Fernández M, Álvarez-Sierra M, Peláez-Campomanes P (2007) Bioclimatic analysis of rodent palaeofaunas reveals severe climatic changes in Southwestern Europe during the Plio-Pleistocene. *Palaeogeogr Palaeoclimatol Palaeoecol* 251:500 - 526

Hernández Fernández M, Vrba E (2005a) Macroevolutionary processes and biomic specialization: testing the resource-use hypothesis. *Evol Ecol* 19:199-119

Hernández Fernández M, Vrba ES (2005b) A complete estimate of the phylogenetic relationships in Ruminantia: a dated species-level supertree of the extant ruminants. *Biol Rev* 80:269-302.

Hernández Fernández M, Vrba E (2005c) Rapoport effect and biomic specialization in African mammals: revisiting the climatic variability hypothesis. *J Biogeogr* 32: 903 - 918

Hernández Fernández M, Vrba ES (2005d) Bodysize, biomic specialization and range size of African large mammals. *J Biogeogr* 32(7):1243-1256

Hernández Fernández M, Cantalapiedra JL, Gómez Cano AR. Plio-Pleistocene climatic change had a major impact on the assembly and disassembly processes of Iberian rodent communities. *Palaeobiodiver Palaeoenviron* 1-18

Hoffmann AA, Sgrò CM (2011) Climate change and evolutionary adaptation. *Nature* 470 (7335):479-485

Holdridge LR (1967) *Life zone ecology*. Tropical Science Center, San Jose, Costa Rica.

Holmes DJ, Austad SN (1995) Birds as animal models for the comparative biology of aging: a prospectus. *J Gerontol A Biol Sci Med Sci* 50 (2):B59-66

Hope S (2002) The Mesozoic radiation of Neornithes. In: Chiappe LM, Witmer LM (eds) *Mesozoic birds: above the heads of dinosaurs*. University of California Press, Berkeley, p 520

Hou L, Chiappe LM, Zhang F, Chuong C-M (2004) New Early Cretaceous fossil from China documents a novel trophic specialization for Mesozoic birds. *Naturwissenschaften* 91 (1):22-25

Houde P (1987) Critical evaluation of DNA hybridization studies in avian systematics. *The Auk*:17-32

Huxley TH (1868) Remarks upon *Archaopteryx lithographica*. *Proc R Soc Lond* 16:243-248

Huxley TH (1870) Further evidence of the affinity between the dinosaurian reptiles and birds. *Q J Geol Soc* 26 (1-2):12-31

Jacobs BF (2004) Palaeobotanical studies from tropical Africa: relevance to the evolution of forest, woodland and savannah biomes. *Philos Trans R Soc B* 359 (1450):1573-1583

Janzen DH (1967) Why mountain passes are higher in the tropics. *Am Nat*:233-249

Jara-Arancio P, Arroyo MTK, Guerrero PC, Hinojosa LF, Arancio G, Méndez MA (2014) Phylogenetic perspectives on biome shifts in *Leucocoryne* (Alliaceae) in relation to climatic niche evolution in western South America. *J Biogeogr* 41 (2):328-338

Jaramillo C, Cárdenas A (2013) Global warming and neotropical rainforests: A historical perspective. *Annu Rev Earth Pl Sc* 41:741-766

Jarvis ED, Mirarab S, Aberer AJ, Li B, Houde P, Li C, Ho SYW, Faircloth BC, Nabholz B, Howard JT, Suh A, Weber CC, da Fonseca RR, Li J, Zhang F, Li H, Zhou L, Narula N, Liu L, Ganapathy G, Boussau B, Bayzid MS, Zavidovych V, Subramanian S, Gabaldón T, Capella-Gutiérrez S, Huerta-Cepas J, Rekepalli B, Munch K, Schierup M, Lindow B, Warren WC, Ray D, Green RE, Bruford MW, Zhan X, Dixon A, Li S, Li N, Huang Y, Derryberry EP, Bertelsen MF, Sheldon FH, Brumfield RT, Mello CV, Lovell PV, Wirthlin M, Schneider MPC, Prosdocimi F, Samaniego JA, Velazquez AMV, Alfaro-Núñez A, Campos PF, Petersen B, Sicheritz-Ponten T, Pas A, Bailey T, Scofield P, Bunce M, Lambert DM, Zhou Q, Perelman P, Driskell AC, Shapiro B, Xiong Z, Zeng Y, Liu S, Li Z, Liu B, Wu K, Xiao J, Yinqi X, Zheng Q, Zhang Y, Yang H, Wang J, Smeds L, Rheindt FE, Braun M, Fjeldsa J, Orlando L, Barker FK, Jønsson KA, Johnson W, Koepfli K-P, O'Brien S, Haussler D, Ryder OA, Rahbek C, Willerslev E, Graves GR, Glenn TC, McCormack J, Burt D, Ellegren H, Alström P, Edwards SV, Stamatakis A, Mindell DP, Cracraft J, Braun EL, Warnow T, Jun W, Gilbert MTP, Zhang G (2014)

Whole-genome analyses resolve early branches in the tree of life of modern birds. *Science* 346 (6215):1320-1331.

Jetz W, Fine PVA (2012) Global gradients in vertebrate diversity predicted by historical area-productivity dynamics and contemporary environment. *PLoS Biol* 10 (3):e1001292.

Jetz W, Freckleton RP, McKechnie AE (2008) Environment, migratory tendency, phylogeny and basal metabolic rate in birds. *PLoS ONE* 3 (9):1-9

Jetz W, Rahbek C (2002) Geographic Range Size and Determinants of Avian Species Richness. *Science* 297 (5586):1548-1551.

Jetz W, Thomas HH, Joy JB, Hartman K, Mooers AO (2012) The global diversity of birds in space and time. *Nature* 491 (7424):444-448

Jønsson KA, Fjeldså J (2006) A phylogenetic supertree of oscine passerine birds (Aves: Passeri). *Zool Scr* 35 (2):149-186

Kennedy JD, Wang Z, Weir JT, Rahbek C, Fjeldså J, Price T (2014) Into and out of the tropics: the generation of the latitudinal gradient among New World passerine birds. *J Biogeogr*:1-12. doi:10.1111/jbi.12346

Kozak KH, Wiens JJ (2012) Phylogeny, ecology, and the origins of climate-richness relationships. *Ecology* 93 (sp8):S167-S181

Ksepka DT (2014) Evolution: A Rapid Flight towards Birds. *Curr Biol* 24 (21):R1052-R1055

Ksepka DT, Boyd CA (2012) Quantifying historical trends in the completeness of the fossil record and the contributing factors: an example using Aves. *Paleobiology* 38 (1):112-125

Ksepka DT, Ware JL, Lamm KS (2014) Flying rocks and flying clocks: disparity in fossil and molecular dates for birds. *Proc R Soc Lond B*: 281 (1788).20140677

Lanfear R, Ho SYW, Love D, Bromham L (2010) Mutation rate is linked to diversification in birds. *Proc Natl Acad Sci USA*: 107(47) 20423-20428

Latham RE, Ricklefs RE (1993) Continental comparisons of temperate-zone tree species diversity. In: Ricklefs RE, Schulter D. *Species diversity in ecological*

communities: historical and geographical perspectives. Unversity of Chicago Press :294-314

Lee MSY, Cau A, Naish D, Dyke GJ (2014) Morphological clock in paleontology, and a Mid-Cretaceous origin of crown Aves. *Syst Biol* 63 (3):442-449

Li D-S, Sullivan C, Zhou Z-H, Zhang F-C (2010) Basal birds from China: a brief review. *Chinese Birds* 1 (2):83-96

Li Z, Zhou Z, Wang M, Clarke JA (2014) A new specimen of large-bodied basal Enantiornithine *Bohaiornis* from the Early Cretaceous of China and the inference of feeding ecology in Mesozoic birds. *J Paleontol* 88 (1):99-108

Livezey BC (1997) A phylogenetic analysis of basal Anseriformes, the fossil *Presbyornis* and the interordinal relation- ships of waterfowl. *Zool J Linn Soc* 121:361-428

Livezey BC, Zusi RL (2007) Higher-order phylogeny of modern birds (Theropoda, Aves: Neornithes) based on comparative anatomy. II. Analysis and discussion. *Zool J Linn Soc* 149:1-95

Loewen MA, Irmis RB, Sertich JJ, Currie PJ, Sampson SD (2013) Tyrant dinosaur evolution tracks the rise and fall of Late Cretaceous oceans. *PLoS ONE* 8(11): e79420.

Longrich N (2006) Structure and function of hindlimb feathers in Archaeopteryx lithographica. *Paleobiology* 32 (3):417-431

Longrich N (2009) An ornithurine-dominated avifauna from the Belly River Group (Campanian, Upper Cretaceous) of Alberta, Canada. *Cretac Res* 30 (1):161-177

Longrich NR, Tokaryk T, Field DJ (2011) Mass extinction of birds at the Cretaceous–Paleogene (K–Pg) boundary. *Proc Natl Acad Sci USA* 108 (37):15253-15257

Losos JB (2008) Phylogenetic niche conservatism, phylogenetic signal and the relationship between phylogenetic relatedness and ecological similarity among species. *Ecol Lett* 11 (10):995-1003

Losos JB, Glor RE (2003) Phylogenetic comparative methods and the geography of speciation. *Trends Ecol Evol* 18 (5):220-227

Louchart A, Viriot L (2011) From snout to beak: the loss of teeth in birds. Trends *Ecol Evol* 26 (12):663-673

Maguire KC, Stigall AL (2008) Paleobiogeography of Miocene Equinae of North America: A phylogenetic biogeographic analysis of the relative roles of climate, vicariance, and dispersal. *Palaeogeogr Palaeoclimatol Palaeoecol* 267 (3–4):175-184. doi:http://dx.doi.org/10.1016/j.palaeo.2008.06.014

Marshall AJ (2013) *Biology and comparative physiology of birds*, vol 1. Academic Press

Martin LD (1984) A new hesperornithid and the relationships of the Mesozoic birds. *Trans Kans Acad Sci* (1903):141-150

Martin LD, Stewart JD (1977) Teeth in *Ichthyornis* (Class: Aves). *Science* 195 (4284):1331-1332

Martin TE (1995) Avian life history evolution in relation to nest sites, nest predation, and food. *Ecol Monogr* 65 (1):101-127

Martyniuk MP (2012) *A field guide to Mesozoic birds and other winged dinosaurs*. PanAves, Vernon, New Jersey

Matzke NJ (2014) *Package "BioGeoBEARS" BioGeography with Bayesian (and Likelihood) Evolutionary Analysis in R scripts*. Version 0.2.1 edn

Mayr E (1940) Speciation phenomena in birds. *Am Nat*:249-278

Mayr G (2007) Avian higher-level phylogeny: well-supported clades and what we can learn from a phylogenetic analysis of 2954 morphological characters. *J Zool Syst Evol Res* 46 (1):63-72

Mayr G (2009) *Paleogene fossil birds*. Springer, Heilderberg

Mayr G (2014) The origins of crown group birds: Molecules and Fossils. *Palaeontology* 57 (2):231-241

Mayr G, Clarke J (2003) The deep divergences of neornithine birds: a phylogenetic analysis of morphological characters. *Cladistics* 19:527-553

Mayr G, Pohl B, Hartman S, Peters DS (2007) The tenth skeletal specimen of *Archaeopteryx*. *Zool J Linn Soc* 149 (1):97-116

Mayr G, Pohl B, Peters DS (2005) A well-preserved *Archaeopteryx* specimen with theropod features. *Science* 310 (5753):1483-1486

McGuire JA, Witt CC, Remsen JV, Corl A, Rabosky DL, Altshuler DL, Dudley R (2014) Molecular phylogenetics and the diversification of hummingbirds. *Curr Biol* 24 (8):910-916

McKitrick MC, Zink RM (1988) Species concepts in ornithology. *Condor*:1-14

Mendoza ÁM, Ospina OE, Cárdenas-Henao H, García-R JC (2015) A likelihood inference of historical biogeography in the world's most diverse terrestrial vertebrate genus: Diversification of direct-developing frogs (Craugastoridae: *Pristimantis*) across the Neotropics. *Mol Phylogenet Evol* 85:50-58

Meredith RW, Zhang G, Gilbert MTP, Jarvis ED, Springer MS (2014) Evidence for a single loss of mineralized teeth in the common avian ancestor. Science 346 (6215):1254390

Mitchell JS, Makovicky PJ (2014) Low ecological disparity in early Cretaceous birds. *Proc R Soc Lond B* 281:20140608

Mittelbach GG, Schemske DW, Cornell HV, Allen AP, Brown JM, Bush MB, Harrison SP, Hurlbert AH, Knowlton N, Lessios HA, McCain CM, McCune AR, McDade LA, McPeek MA, Near TJ, Price TD, Ricklefs RE, Roy K, Sax DF, Schluter D, Sobel JM, Turelli M (2007) Evolution and the latitudinal diversity gradient: speciation, extinction and biogeography. *Ecol Lett* 10 (4):315-331. doi:10.1111/j.1461-0248.2007.01020.x

Mlíkovský Jí (2002) *Cenozoic Birds of the World*, vol Part 1: Europe. Praha: Ninox press

Mooers AØ, Vamosi SM, Schluter D (1999) Using phylogenies to test macroevolutionary hypotheses of trait evolution in cranes (Gruinae). *Am Nat* 154 (2):249-259

Morales J, Cantalapiedra JL, Valenciano A, Hontecillas D, Fraile S, Yelo BAG, *et al*. (2015) The fossil record of the Neogene Carnivore Mammals from Spain. *Palaeobiodivers Palaeoenviron* 95(3):373-86.

Moreno Bofarull A, Arias Royo A, Hernández Fernández M, Ortiz-Juareguizar E, Morales J (2008) Influence of continental history on the ecological specialization and macroevolutionary procesess in the mammalian assemblage of South America: Differences between small and large mammals. *BMC Evol Biol* 8 (97):1-18

Moritz C, Patton J, Schneider C, Smith T (2000) Diversification of rainforest faunas: an integrated molecular approach. *Annu Rev Ecol Syst*:533-563

Morlon H (2014) Phylogenetic approaches for studying diversification. *Ecol Lett* 17 (4):508-525

Naish D (2014) The fossil record of bird behaviour. *J Zool* 292 (4):268-280

Near TJ, Dornburg A, Eytan RI, Keck BP, Smith WL, Kuhn KL, Moore JA, Price SA, Burbrink FT, Friedman M (2013) Phylogeny and tempo of diversification in the superradiation of spiny-rayed fishes. *Proc Natl Acad Sci USA* 110 (31):12738-12743

Newton I (2003) *The speciation and biogeography of birds.* Academic Press, London & San Diego

Noonan BP, Chippindale PT (2006) Dispersal and vicariance: The complex evolutionary history of boid snakes. *Mol Phylogenet Evol* 40:347-358

Norell M, Ji Q, Gao K, Yuan C, Zhao Y, Wang L (2002) Palaeontology:"Modern" feathers on a non-avian dinosaur. *Nature* 416 (6876):36-37

O'Connor JK, Zhou Z, Xu X (2011) Additional specimen of *Microraptor* provides unique evidence of dinosaurs preying on birds. *Proc Natl Acad Sci USA* 108 (49):19662-19665

O'Connor JK (2009) *A systematic review of Enantiornithes (Aves: Ornithothoraces).* Ph.D Thesis. Faculty of the Graduate School.University of Southern California

O'Connor JK, Chiappe LM (2011) A revision of enantiornithine (Aves: Ornithothoraces) skull morphology. *J Syst Palaeontol* 9 (1):135-157

O'Connor JK, Zhang Y, Chiappe LM, Meng Q, Quanguo L, Di L (2013) A new enantiornithine from the Yixian Formation with the first recognized avian enamel specialization. *J Vertebr Paleontol* 33 (1):1-12

O´Connor JK, Chiappe LM (2011) A revision of enantiornithine (Aves: Ornithothoraces) skull morphology. *J Syst Palaeontol* 9 (1):135-157

O´Connor JK, Zhou Z (2013) A redescription of *Chaoyangia beishanensis* (Aves) and a comprehensive phylogeny of Mesozoic birds. *J Syst Palaeontol* 11 (7):889-906

O'Connor PM, Claessens LPAM (2005) Basic avian pulmonary design and flow-through ventilation in non-avian theropod dinosaurs. *Nature* 436 (7048):253-256

Olson SL (1985) The fossil record of birds. In: Farner DS, King JR, Parkes KC (eds) *Avian Biology*, vol 8. Academic Press, NewYork, pp 79-238

Organ CL, Shedlock AM, Meade A, Pagel M, Edwards SV (2007) Origin of avian genome size and structure in non-avian dinosaurs. *Nature* 446 (7132):180-184

Ostrom JH (1974) *Archaeopteryx* and the origin of flight. *Q Rev Biol*:27-47

Ostrom JH (1976) *Archaeopteryx* and the origin of birds. *Biol J Linn Soc* 8 (2):91-182

Owen R (1863) On the *Archéoptéryx* of von Meyer, with a description of the fossil remains of a long-tailed species, from the lithographic stone of Solenhofen. *Philos Trans R Soc Lond*:33-47

Pacheco MA, Battistuzzi FU, Lentino M, Aguilar RF, Kumar S, Escalante AA (2011) Evolution of Modern Birds revealed by Mitogenomics: Timing the Radiation and Origin of Major Orders. *Mol Biol Evol* 28 (6):1927-1942

Padian K, Chiappe LM (1998) The origin and early evolution of birds. *Biol Rev Camb Philos Soc* 73 (01):1-42

Padian K, de Ricqlès A (2009) L'origine et l'évolution des oiseaux: 35 années de progrès. *Comptes Rendus Palevol* 8 (2):257-280

Paine RT (1966) Food web complexity and species diversity. *Am Nat*:65-75

Paton T, Haddrath O, Baker AJ (2002) Complete mitochondrial DNA genome sequences show that modern birds are not descended from transitional shorebirds. *Proc R Soc Lond B* 269 (1493):839-846

Pelegrin JS (2010) Dinosaurios en nuestros días: El vuelo y la pluma en la evolución de las aves. *Innovación y Ciencia* 16 (1):26-35

Pelegrin JS, Cantalapiedra JL, Hernández Fernández M (2014a) Macroevolutionary processes in non-passeriform birds (Aves) at the global scale. *Ornithol Sci* (Sup. 13).(Proceedings of the 26th International Ornithological Congress)

Pelegrin JS, Cantalapiedra JL, Hernández Fernández M (2014b) A phylogenetic perspective of the Avian trophic diversification: integrating paleontological

and neontological information. 74th *Meeting of the Society of Vertebrate Paleontology conference proceedings*

Pelegrin JS, Cantalapiedra JL, Hernández Fernández M (2015) The macroevolutionary role of migration for bird occupation of biomes with adverse climatic conditions. In: Domingo L, Domingo MS, Fesharaki O et al. (eds) *Current trends in Paleontology and Evolution*. Madrid-Spain. pp 197-199

Pennell MW, Harmon LJ (2013) An integrative view of phylogenetic comparative methods: connections to population genetics, community ecology, and paleobiology. *Ann N Y Acad Sci* 1289 (1):90-105

Pennington RT, Cronk QC, Richardson JA (2004) Introduction and synthesis: plant phylogeny and the origin of major biomes. *Philos Trans R Soc Lond B* 359 (1450):1455-1464

Penny D, Phillips MJ (2004) The rise of birds and mammals: are microevolutionary processes sufficient for macroevolution? *Trends Ecol Evol* 19 (10):1-7

Pereira SL, Johnson K, Clayton D, Baker A (2007) Mitochondrial and Nuclear DNA Sequences Support a Cretaceous Origin of Columbiformes and a Dispersal-Driven Radiation in the Paleogene. *Syst Biol* 56 (4):656-672

Pettingill OS (2013) *Ornithology in laboratory and field*. Academic Press. Orlando Florida

Phillimore AB, Orme DL, Thomas GH, Blackburn TM, Bennet PM, Gaston KJ, Owens IPF (2008) Sympatric speciation in birds is rare: insights from range data and simulations. *Am Nat* 171 (5):646-657

Pigot AL, Tobias JA (2013) Species interactions constrain geographic range expansion over evolutionary time. *Ecol Lett* 16 (3):330-338

Plana V (2004) Mechanisms and tempo of evolution in the African Guineo–Congolian rainforest. *Philos Trans R Soc B* 359 (1450):1585-1594

Porzecanski AL, Cracraft J (2005) Cladistic analysis of distributions and endemism (CADE): using raw distributions of birds to unravel the biogeography of the South American aridlands. *J Biogeogr* 32 (2):261-275

Prum RO, Brush AH (2002) The evolutionary origin and diversification of feathers. *Quart Rev Bio*l 77 (3):261-295

Pyron RA, Burbrink FT (2012) Extinction, ecological opportunity, and the origins of global snake diversity. *Evolution* 66 (1):163-178

Qiang J, Currie PJ, Norell MA, Shu-An J (1998) Two feathered dinosaurs from northeastern China. *Nature* 393 (6687):753-761

Raup DM, Gould SJ, Schopf TJ, Simberloff DS (1973) Stochastic models of phylogeny and the evolution of diversity. *J Geol*:525-542

Raup DM, Sepkoski JJ (1986) Periodic extinction of families and genera. *Science* 231 (4740):833-836

Ree RH, Smith SA (2008) Maximun likelihood inference of geographic range evolution by dispersal, local extinction and cladogenesis. *Syst Biol* 57 (1):4-14

Rees J, Lindgren J (2005) Aquatic birds from the Upper Cretaceous (Lower Campanian) of Sweden and the biology and distribution of hesperornithiforms. *Palaeontology* 48 (6):1321-1329

Ricklefs RE (2008) The Biome concept in Ecology. In: *The Economy of Nature: A textbook in basic Ecology*. 6 edn. W.H. Freeman & Company, pp 88-111

Rolland J, Jiguet F, Jønsson KA, Condamine FL, Morlon H (2014) Settling down of seasonal migrants promotes bird diversification. Proc R Soc Lond B 281 (1784).20140473

Rosenzweig ML (1995) *Species diversity in space and time*. Cambridge University Press

Salvador RB, Fiorelli LE Water vapor conductance in fossil early bird eggs and non-avian theropods: implications for the evolution of modern birds exposed nest structure. In: *XXII Congreso Brasileiro de Paleontologia, Atas*, 2011. pp 742-745

Sanisidro O, Cantalapiedra JL (2010) Nuevas técnicas paleobiogeográficas aplicadas a la familia Rhinocerotidae (Perissodactyla). In: Moreno-Azanza M, Diaz-Martínez I, Gasca JM, Melero-Rubio M, Rabal-Garcés R, Sauqué V (eds) *Cidaris VIII Encuentro de Jóvenes Investigadores en Paleontología, Volumen de actas*, vol 30. pp 293-298

Sanmartín I, Ronquist F (2004) Southern hemisphere biogeography inferred by event-based models: plant versus animal patterns. *Syst Biol* 53:216-243

Sanz JL, Chiappe LM, Pérez-Moreno BP, Buscalioni AD, Moratalla JJ, Ortega F, Poyato-Ariza FJ (1996) An Early Cretaceous bird from Spain and its implications for the evolution of avian flight. *Nature* 382 (6590):442-444

Sanz JL, Ortega F (2002) The birds from Las Hoyas. *Sci Prog* 85 (2):113-130

Schemske D (2002) Tropical diversity: patterns and processes. In: Chazdon R, Whitmore T (eds) *Ecological and evolutionary perspectives on the origins of tropical diversity: key papers and commentaries*. University of Chicago Press, pp 163-173

Schneider CJ, Smith TB, Larison B, Moritz C (1999) A test of alternative models of diversification in tropical rainforests: ecological gradients vs. rainforest refugia. *Proc Natl Acad Sci USA* 96 (24):13869-13873

Schreiber EA, Burger J (2001) *Biology of marine birds*. CRC Press

Schweizer M, Seehausen O, Güntert M, Hertwig ST (2010) The evolutionary diversification of parrots supports a taxon pulse model with multiple trans-oceanic dispersal events and local radiations. *Mol Phylogenet Evol* 54 (3):984-994

Şekercioğlu CH, Schneider SH, Fay JP, Loarie SR (2008) Climate Change, Elevational Range Shifts, and Bird Extinctions. *Conserv Biol* 22 (1):140-150

Senter P (2006) Scapular orientation in theropods and basal birds, and the origin of flapping flight. *Acta Palaeontol Pol* 51 (2):305

Sepkoski Jr JJ (1993) Ten years in the library: new data confirm paleontological patterns. *Paleobiology*:43-51

Sepkoski Jr JJ (1996) Patterns of Phanerozoic extinction: a perspective from global data bases. In: *Global events and event stratigraphy in the Phanerozoic*. Springer, pp 35-51

Sereno P (1999) The Evolution of Dinosaurs. *Science* 284:2137-2147

Sibley CG, Ahlquist JE (1983) Phylogeny and classification of birds based on the data of DNA-DNA hybridization. In: *Current ornithology*. Springer, pp 245-292

Sibley CG, Ahlquist JE (1990) *Phylogeny and classification of birds: a study in molecular evolution*. Yale University Press, New haven, Conn

Sibley CG, Ahlquist JE, Monroe Jr BL (1988) A classification of the living birds of the world based on DNA-DNA hybridization studies. *The Auk*:409-423

Smith BT, McCormack JE, Cuervo AM, Hickerson MJ, Aleixo A, Cadena CD, Pérez-Emán J, Burney CW, Xie X, Harvey MG (2014) The drivers of tropical speciation. *Nature* 515 (7527):406-409

Smith NA (2015) Sixteen vetted fossil calibrations for divergence dating of Charadriiformes (Aves, Neognathae). *Palaeontol Electron* 18:1-18

Smith NA, Clarke JA (2014) Systematics and evolution of the Pan-Alcidae (Aves, Charadriiformes). *J Avian Biol* 46 (2):125-140

Springer MS, Meredith RW, Gatesy J, Emerling CA, Park J, Rabosky DL, Stadler T, Steiner C, Ryder OA, Janečka JE, Fisher CA, Murphy WJ (2012) Macroevolutionary Dynamics and Historical Biogeography of Primate Diversification Inferred from a Species Supermatrix. *PLoS ONE* 7 (11):e49521.

St John JA, Braun EL, Isberg SR, Miles LG, Chong AY, Gongora J, Dalzell P, Moran C, Bed'Hom B, Abzhanov A (2012) Sequencing three crocodilian genomes to illuminate the evolution of archosaurs and amniotes. *Genome biology* 13 (1):415

Stanley SM (1975) A theory of evolution above the species level. *Proc Natl Acad Sci USA* 72 (2):646-650

Stein RW, Brown JW, Mooers AØ (2015) A molecular genetic time scale demonstrates Cretaceous origins and multiple diversification rate shifts within the order Galliformes (Aves). *Mol Phylogenet Evol* 92:155-164

Tavares ES, Baler AJ, Pereira SL, Miyaki CY (2006) Phylogenetic Relationships and Historical Biogeography of Neotropical Parrots (Psittaciformes: Psittacidae: Arini) Inferred from Mitochondrial and Nuclear DNA Sequences. *Syst Biol* 55 (3):454-470

Thomas G, Will MA, Székely T (2004) A supertree approach to shorebird phylogeny. *BMC Evol Biol* 4 (28):1-18

Tiffney BH (2008) Phylogeography, fossils and northern hemisphere biogeography: the role of physiological uniformitarianism. *Ann Mo Bot Gard* 95 (1):135-143

Tingley R, Dubey S (2012) Disparity in the timing of vertebrate diversification events between the northern and southern hemispheres. *BMC Evol Biol* 12 (1):244

Toussaint EFA, Condamine FL, Kergoat GJ, Caodevielle-Dulac C, Barbut J, Silvain JF, Le Ru BP (2012) Palaeoenviromental shifts drove the adaptive radiation of a noctuid stemborer tribe (Lepidoptera, Noctuidae, Apameini) in the Miocene. *PLoS ONE* 7(7): e41377

Tris JP, Bensch S, Carbonell R, Helbig A, Tellería JL (2004) Historical diversification of migration patterns in a passerine bird. *Evolution* 58 (8):1819-1832

Turner AH, Makovicky PJ, Norell MA (2012) A review of dromaeosaurid systematics and paravian phylogeny. *Bull Am Mus Nat Hist*:1-206

Turner D (2011) *Paleontology: a philosophical introduction.* Cambridge University Press

van Tuinen M, Butvill DB, Kirsch JA, Hedges SB (2001) Convergence and divergence in the evolution of aquatic birds. *Proc R Soc Lond B* 268 (1474):1345-1350

van Tuinen M, Hedges SB (2001) Calibration of avian molecular clocks. *Mol Biol Evol* 18 (2):206-213

van Tuinen M, Sibley CG, Hedges SB (1998) Phylogeny and biogeography of Ratite birds inferred from DNA sequences of the mitochondrial ribosomal genes. *Mol Biol Evol* 15 (4):370-376

van Tuinen M, Sibley CG, Hedges SB (2000) The early history of modern birds inferred from DNA sequences of nuclear and mitochondrial ribosomal genes. *Mol Biol Evol* 17 (3):451-457

van Tuinen M, Waterhouse D, Dyke GJ (2004) Avian molecular systematics on the rebound: a fresh look at modern shorebird phylogenetic relationships. *J Avian Biol* 35 (3):191-194.

Vrba ES (1985) Environment and evolution: alternative causes of the temporal distribution of evolutionary events. *S Afr J Sci* 81:229 - 236

Vrba ES (1993) Turnover-pulses, the Red Queen, and related topics. *Am J Sci* 293:418 - 452

Vrba ES (1980) Evolution, species and fossils: how does life evolve? *S Afr J Sci* 76:61-84

Vrba ES (1987) Ecology in relation to speciation rates; some case histories of Miocene-Recent mammal Clades. *Evol Ecol* 1:283-300

Vrba ES (1992) Mammals as a key to evolutionary theory. J Mammal 73:1-28

Vrba ES (1995) On the connections between paleoclimate and evolution. In: Vrba ES, Denton GH, Partridge TC, Burckle LH (eds) *Paleoclimate and Evolution, with Emphasis of Human Origins*. Yale University Press, New Haven, USA, pp 24-45

Vrba ES (1999) Habitat theory in relation to the evolution in African Neogene biota and hominids. In: Bromage TG, Schrenk F (eds) *African biogeography, climate change, and the human evolution*. Oxford University Press, New York, pp 19-39

Vrba ES (2004) Mass turnover and heterochrony events in response to physical change. *Paleobiology* 31 (Sup 5):157-174

Vrba ES, Gould SJ (1986) The hierarchical expansion of sorting and selection: sorting and selection cannot be equated. *Paleobiology*:217-228

Walker CA (1981) New subclass of birds from the Cretaceous of South America. *Nature* 292 (5818):51-53

Wallace AR (1878) *Tropical nature, and other essays.* Macmillan and Company,

Walter H (1970) *Vegetationszonen und klima*. Eugen Ulmer, Stuttgart

Wang M, O'Connor JK, Zhou Z (2014) A new robust enantiornithine bird from the Lower Cretaceous of China with scansorial adaptations. *J Vertebr Paleontol* 34 (3):657-671

Wang M, Zheng X, O'Connor JK, Lloyd GT, Wang X, Wang Y, Zhang X, Zhou Z (2015) The oldest record of ornithuromorpha from the early cretaceous of China. *Nature communications* 6:6987

Webb DM, Moore WS (2005) A phylogenetic analysis of woodpeckers and their allies using 12S, Cyt b, and COI nucleotide sequences (class Aves; order Piciformes). *Mol Phylogenet Evol* 36 (2):233-248.

Webb TJ, Gaston KJ (2000) Geographic range size and evolutionary age in birds. *Proc R Soc Lond B* 267 (1455):1843-1850

Wheelwright NT (1985) Fruit size, gape width, and the diets of fruit-eating birds. *Ecology* 66 (3):808-818

Whittaker RH (1975) *Communities and Ecosystems*. 2nd edn. Macmillan, New York

Wiens JJ (2004) Speciation and ecology revisited: phylogenetic niche conservatism and the origin of species. *Evolution* 58 (1):193-197

Wiens JJ, Ackerly DD, Allen AP, Anacker BL, Buckley LB, Cornell HV, Damschen EI, Davies TJ, Grytnes J-A, Harrison SP, Hawkins BA, Holt RD, McCain CM, Stephens PR (2010) Niche conservatism as an emerging principle in ecology and conservation biology. *Ecol Lett* 13:1310-1324

Wiens JJ, Donoghue MJ (2004) Historical biogeography, ecology and species richness. *Trends Ecol Evol* 19 (12):639-644

Wiens JJ, Graham CH (2005) Niche Conservatism: Integrating Evolution, Ecology, and Coservation Biology. *Ann Rev Ecol Evol Syst* 36:519-539

Wilson LE, Chin K, Cumbaa S, Dyke G (2011) A high latitude hesperornithiform (Aves) from Devon Island: palaeobiogeography and size distribution of North American hesperornithiforms. *J Syst Palaeontol* 9 (1):9-23

Wink M, Seibold I, Lotfikhah F, Bednarek W (1998) Molecular systematics of holarctic raptors (Order Falconiformes). *Holarctic birds of prey* 29:48

Wong K (2011) A biogeographic history of Southeast Asian rainforests. In: *Managing the Future of Southeast Asia's Valuable Tropical Rainforests*. Springer, pp 21-55

Woodward F, Lomas M, Kelly C (2004) Global climate and the distribution of plant biomes. *Philos Trans R Soc Lond B* 359 (1450):1465-1476

Wright DH (1983) Species – Energy theory: an extension of species – area theory. *Oikos* 41:496-506

Xu X, Zhang F (2005) A new maniraptoran dinosaur from China with long feathers on the metatarsus. *Naturwissenschaften* 92 (4):173-177

Xu X, Zhao Q, Norell M, Sullivan C, Hone D, Erickson G, Wang X, Han F, Guo Y (2009) A new feathered maniraptoran dinosaur fossil that fills a morphological gap in avian origin. *Chin Sci Bull* 54 (3):430-435

Xu X, Zheng X, You H (2010) Exceptional dinosaur fossils show ontogenetic development of early feathers. *Nature* 464 (7293):1338-1341

Xu X, Zhou Z, Wang X, Kuang X, Zhang F, Du X (2003) Four-winged dinosaurs from China. *Nature* 421 (6921):335-340

You H-l, Lamanna MC, Harris JD, Chiappe LM, O'Connor J, Ji S-a, Lü J-c, Yuan C-x, Li D-q, Zhang X (2006) A nearly modern amphibious bird from the Early Cretaceous of northwestern China. *Science* 312 (5780):1640-1643

Yu Y, Harris AJ, Blair C, He X (2015) RASP (Reconstruct Ancestral State in Phylogenies): a tool for historical biogeography. *Mol Phylogenet Evol* 87:46-49

Zelenitsky DK, Therrien F, Erickson GM, DeBuhr CL, Kobayashi Y, Eberth DA, Hadfield F (2012) Feathered non-avian dinosaurs from North America provide insight into wing origins. *Science* 338 (6106):510-514

Zhang F, Zhou Z, Xu X, Wang X, Sullivan C (2008) A bizarre Jurassic maniraptoran from China with elongate ribbon-like feathers. *Nature* 455 (7216):1105-1108

Zheng X, Zhou Z, Wang X, Zhang F, Zhang X, Wang Y, Wei G, Wang S, Xu X (2013) Hind wings in basal birds and the evolution of leg feathers. *Science* 339 (6125):1309-1312

Zhou Z (2014) Dinosaur Evolution: Feathers Up for Selection. *Curr Biol* 24 (16):R751-R753

Zhou Z, Zhang F (2003) *Jeholornis* compared to *Archaeopteryx*, with a new understanding of the earliest avian evolution. *Naturwissenschaften* 90 (5):220-225

Zhou Z, Zhang F (2005) Discovery of an ornithurine bird and its implication for Early Cretaceous avian radiation. *Proc Natl Acad Sci USA* 102 (52):18998-19002

Zhou Z, Zhang F (2006) A beaked basal ornithurine bird (Aves, Ornithurae) from the Lower Cretaceous of China. *Zool Scr* 35 (4):363-373

Zhou Z, Zhang F (2007) Mesozoic birds of China: a synoptic review. *Frontiers of Biology in China* 2 (1):1-14

2 Biomic specialization

2 Ecological specialization and climate changes regulate global evolutionary patterns in non-passerine birds

" The equatorial regions are, as far as the history of past and present life, [...] an older world than the shown in temperate zones, where , by comparison, the laws that have governed the progressive development of life have operated with little control over countless time "

Alfred Russel Wallace (1878)

"... Most past ecosystems were constantly and repeatedly forced by climatic changes to alter, dismantle, and reconstitute"

Elisabeth S. Vrba (1993)

ABSTRACT

Although birds form the most diverse group of terrestrial vertebrates and their biology has been extensively documented, our understanding of their evolutionary history and its connection to current geographic distribution patterns is still incomplete. By combining extensive ecological new data with simulations, we demonstrate that patterns of biome occupation in birds are congruent with those previously reported for mammals. Overall, species restricted to a single biome are by far more abundant than expected by random evolutionary patterns. Non-migratory species showed a higher biome specialization than migratory species. Herbivorous species tend to be significantly more biome-restricted than faunivorous species, the omnivorous birds being found at an intermediate position. Biome specialists are particularly concentrated in extreme biomes as tropical rainforests, subtropical deserts, steppes and tundras.

These findings highlight the universality of the resource-use hypothesis, which links climate forcing and different degrees of ecological specialization to the observed distribution of species across the globe.

Key words: Aves, Biome, Extinction, Macroecology, Macroevolution, Speciation.

2.2. INTRODUCTION

Evolution of species is undoubtedly linked to historical patterns of environmental change (Cracraft 1973; Barnosky 2001; Lister 2004; Weir and Schluter 2004; Douglas et al. 2006; Hawkins et al. 2006; Buckley and Jetz 2007; Roelants et al. 2007; Hawkins et al. 2012; Gómez Cano et al. 2013). The proposed main drivers of speciation and extinction are physical and environmental variations such as shifts in climate and tectonics acting at wide scales (Vrba 1992, 1995; Benton 2009; Finarelli and Badgley 2010), which inevitably have a major footprint in present species diversity and ecological gradients. Current patterns of biodiversity have been explored for decades and correlated with various factors such as niche conservatism (Ramos Pereira and Palmeirim 2013), clade age (Hawkins et al. 2006; Buckley et al. 2010; Kennedy et al. 2014), disparate diversification rates (Bromham and Cardillo 2003), as well as present climate (Francis and Currie 2003) among others (Vrba 1980; Willig et al. 2003; Voelker et al. 2010; Wiens et al. 2010; Fjeldsa° 2012; Jetz and Fine 2012; Araújo et al. 2013; Vrba 1987). But all the particularities and the heterogeneity observed in these approaches still need an integrative explanation [Hawkins 2006]. We here revisit deep-time evolutionary perspectives that merges species ecology and geographic diversification gradients with processes of past physical change to complement contemporary macroecological perceptions of the species distributions seen today across the globe.

In particular, we focus on the importance of the biome as a relevant macroecological and macroevolutionary unit (Vrba 1987; Hernández Fernández 2001; Jetz and Fine 2012) based on the idea that the degree of biome specialization of species has an important role on differential diversification among clades: the so-called resource-use hypothesis (Vrba 1987). Specialists in resources associated to one particular biome should experience higher speciation rates through vicariance events and directional selection due to fragmentation of biome distribution in relation with global environmental or geological changes. By contrast, biome generalists are more ecologically flexible and should not be substantially affected by fragmentation of their

geographical distributions and subsequent speciation in relation to global changes (Vrba 1987). However, although this resource-use hypothesis has been supported by previous studies based on both extinct and extant mammalian faunas (Vrba 1987; Hernández Fernández and Vrba 2005; Moreno Bofarull et al. 2008; Cantalapiedra et al. 2011; Gómez Cano et al. 2013), its general relevance for the evolution and their impact on the species gradients of other terrestrial organisms remains untested.

In this context, birds are a group of great interest for the analysis and study of macroecological and macroevolutionary models (Cardillo 1999; Penny and Phillips 2004; Cardillo et al. 2005; Diniz-Filho et al. 2007; Hawkins et al. 2007; Sibly et al. 2012) and, particularly, to test the universality of the resource-use hypothesis. They are the most abundant group of terrestrial vertebrates with near 10,000 extant species, distributed in all ecosystems over the world, and many aspects of their very diverse biology and ecology are widely known (Del Hoyo et al. 1992, 1994, 1996, 1997, 1999, 2001, 2002). Additionally, the particular characteristics of this group –mostly flying organisms including a significant number of large distance migrant species– allow for the study of the influence of high dispersal abilities in the general incidence of the resource-use hypothesis.

Therefore, for the first time here, we tested several subsidiary predictions of the resource-use hypothesis in all world non-passerine bird species (3951): 1) given a clade, we should find more biome specialist species than expected by chance, due to their higher rates of speciation; 2) different clades are expected to show different degrees of specialization, due to the differential distribution of their resources, particularly in relation to dietary requirements; 3) we should expect higher proportion of stenobiomic species in biomes placed in the extremes of the global climatic gradient, which underwent a higher degree of fragmentation and contraction during climatic fluctuations (e.g., Milankovitch cycles), since populations in those biomes are subject to a high incidence of vicariance. We tested these predictions using the biomic specialization index (BSI), which is based in the number of inhabited biomes by each species (Hernández Fernández and Vrba 2005).

Drawing from an extensive review of ecological literature, we compiled a dataset including biome occupation, diet and migratory behavior for all non-passerine birds. Using Monte Carlo simulations, we tested whether the observed distribution of bird species across biomes is different from a scenario where biome specialization is independent from clades, biomes and diets. We found that the distribution of species restricted to a single biome is consistent with the predictions derived from the

resource-use hypothesis and resembles those previously reported for mammals. There are more species restricted to a single biome (biome specialists) than expected under random simulations and these biome specialists are preferentially associated to extreme biomes. Although this pattern is maintained across different ecological types, there are differences associated to migratory status and diet. Non-migratory species showed a higher biome specialization than migratory species. Additionally, herbivorous species tend to be significantly more biome-restricted than faunivorous species, the omnivorous birds being found at an intermediate position.

2.3. MATERIALS AND METHODS

2.3.1. Data and study scale

This research was conducted at the global scale, considering all non-passerine birds (3951 species), which are included in 99 families. The basis of our study is the geographic distribution of each species. Distribution areas due to introduction by humans were excluded and species that became extinct in the last two centuries were included. For phylogenetic consistency, we followed the families-level taxonomy of Howard & Moore (Howard and Moore 2013). Information about the geographic distributions, dietary and migratory habits of birds species was gathered from Del Hoyo and co-workers (Del Hoyo et al. 1992, 1994, 1996, 1997, 1999, 2001, 2002) and refined with additional information from IUCN Red List (IUCN 2012) and BirdLife International Database (International. 2013).

2.3.2. Bioclimatic characterization of the species

Based on the distribution of its breeding area across the world, we computed the biomic specialization index (BSI) (Hernández Fernández and Vrba 2005) for each bird species, which indicates the number of inhabited climate zones (biomes). Biome occupation was established following the biomes defined and classified by Walter (Walter 1970) (Table 1). The decision on the number of climate zones inhabited by a species was based on the following. If 15% or more of the geographical range of a species is situated within a climate zone, the species was recorded as present in that climate zone. Since some climatic dominions are small enough to comprise less than 15% of the total distribution ranges of species with large range sizes, a species was also recorded as present in a specific climate zone if it inhabits 50% or more of one climatic dominion (Hernández Fernández 2001). We also considered those species inhabiting mountainous ranges as adapted to the biomes represented by analogous climatic series

Table 1. Biome typology used and its correspondence with vegetation types in the world (Modified from Walter 1970 , we consider II/III as a independient zonobiome -see Chapter1-).

Biome	
I	Evergreen tropical rainforest
II	Tropical deciduous woodland
II/III	Savanna
III	Subtropical desert
IV	Sclerophyllous woodland and shrubland
V	Temperate evergreen forest
VI	Broad-leaf deciduous forest
VII	Steppe/cold desert
VIII	Boreal coniferous forest (Taiga)
IX	Tundra.

of altitudinal gradients, since these habitats present similar vegetation physiognomy, ecological pressures and fragmentation dynamics during the climatic changes and fluctuations (Cantalapiedra et al. 2011).

Biome specialists (stenobiomic species) were defined as species that inhabit only one biome, hence has a BSI = 1(Hernández Fernández and Vrba 2005). On the contrary, generalists (eurybiomic species) were defined as those with BSI > 1, been potentially present in up to ten biomes. In turn, eurybiomic species can be subdivided in two categories: "semi-eurybiomic species" (1 < BSI < 5), and "extreme eurybiomic species" (BSI ≥ 5) (Hernández Fernández and Vrba 2005).

2.3.3. Ecological chraracterization of the species traits

Since they are related to niche breath and dispersal capabilities, migratory status and diet are two factors that may affect the pattern of biome occupation. Thus, we constructed a database with dietary information and migratory status for all the species of non-passeriform birds as recorded in the literature. We codified for three dietary categories: faunivores (n = 2021), with a food source coming mainly from animal protein; herbivores (n = 1473), feeding mainly on plants (leaves, flowers, nectar, fruits or seeds); and omnivores (n = 457), which obtain their nourishment from both animal and plant material in a significant proportion. Many species present occasional

or seasonal feeding on animal protein (Gill 2007), but these were here coded as herbivores when they mainly feed on plants during most of the year. Regarding the migratory status, we considered species as migratory when they present a well-distinguished breeding area (n = 704) and non-migratory when there are no differences between breeding and wintering areas (n = 3247). Finally, for the species with aquatic habits and water-related distribution, BSI was codified based on their breeding area.

2.3.4. Analyses

We tested the prediction that there should be an uneven distribution of biome specialists across clades and biomes and that some biomes should show higher incidence of these specialists than others using Monte Carlo simulations (MC). We compared the observed abundance of specialists and generalists with null models where the biome occurrence for each species was randomly distributed (Hernández Fernández and Vrba 2005). Since particular ecological features of each biome determine species richness (Jetz and Fine 2012), Importantly, in each biome specific ecological features have an effect on species richness in such a way that there is no reason to consider that all the biomes must have the same number of species in the null model. Due this, we conducted a randomization that places species in biomes randomly while constraining the observed species richness in each biome. The null models were obtained from 10,000 simulations. The significance (*p*-value) of the observed trends was assessed comparing the real against the simulated values (Hernández Fernández and Vrba 2005). Besides running the MC analyses for non-passerine birds as a whole (n = 3951), we also explored the potential influence of migration in the observed patterns analyzing the migratory (n = 704) and non-migratory (n = 3247) non-passerines independently.

The second prediction of the resource-hypothesis states that some clades should be more generalist than other groups because the resources they need to survive may be found in environments that differ vastly in climate. A special emphasis has been put in dietary differences (Vrba 1987; Hernández Fernández and Vrba 2005; Moreno Bofarull et al. 2008; Vrba 1980) and, therefore, we might expect differences in the patterns of specialization among birds with different diets. In particular, herbivorous lineages should harbor a higher proportion of specialist species than faunivorous lineages because herbivores are usually more restricted to feeding on plant species associated to specific climatic conditions. Therefore, we performed independent MC analyses for each family of non-passerine birds with more than 10 species (50 families, n=3778 species) as well as for species included in each of the three dietary groups. In

the family analyses we also performed independent MC analyses including and excluding migratory species.

Finally, the third prediction tested here suggests that biomes that underwent a higher degree of fragmentation and expansion due to climatic cycles should have a higher proportion of stenobiomic species than the rest of biomes. Particularly, the resource-use hypothesis predicts that biomes placed in the extremes of the global climatic gradient such as equatorial rainforest (I), desert (III), steppe (VII) and tundra (IX) should have more specialist species than transitional biomes. To evaluate this prediction, we employed the same MC simulations performed previously for all non-passerines and 50 non-passerine families independently. The null distributions of the frequency estimates for each analysis resulted from 10,000 random samples of proportions of biome specialist species in each biome. All the analysis were performed with R (R Development Core Team 2013).

2.3. RESULTS AND DISCUSSION

2.3.1. Specialization patterns

Our results show that the frequency distribution of specialization for the non-passerine birds is strongly right-skewed (Fig. 1A). The mean BSI is 2.3, with 38.7% of species inhabiting only one biome (BSI = 1), which is significantly higher than the expected proportion under random processes (Fig. 1A and Table 2). The proportions of semi-eurybiomic species (BSI = 2-4) are significantly lower than expected from random models (Fig. 1A and Table 2). These results agree with the first prediction of the resource-use hypothesis and are broadly consistent with the patterns obtained for mammalian faunas (Cantalapiedra et al. 2011; Hernández Fernández and Vrba 2005; Moreno Bofarull et al. 2008). By contrast, a mere 9.86% of the species inhabit five or more different biomes, and only one species (0.03%) showed the ecological versatility to occupy all the terrestrial biomes: the peregrine falcon (*Falco peregrinus*). This raptor species is an important predator adapted to a wide spectrum of environmental conditions with various subspecies inhabiting from the tundra to the rainforest (Del Hoyo et al. 1994, 1999; Gaston et al. 2004; Worgester and Ydenberg 2008). Despite their lower proportions, extreme-eurybiomic species (BSI $\geq$ 5) mostly tend to be significantly overrepresented (Fig. 1A and Table 2). Overall, since the extinction rates are lower in extreme eurybiomic species than in semi-eurybiomic species, the former may have experimented a net increase in species over time although their rates of

vicariance and speciation are very low, these results are also agree with the tendencies obtained for extinct and recent mammals (Hernández Fernández and Vrba 2005).

Migratory birds showed a pattern that resembles the general trend of the non-passerines, with a proportion of biome specialist species (32.5%) significantly above the null expectation. However, the migratory species revealed significantly higher values of BSI than non-migratory birds (Fig. 1B-D). We suggest that, although migratory species are constrained by their reproductive requirements in their breeding areas, the competition with resident birds in winter quarters and the relative distance between the breeding and the wintering zones (Bell 2000; Newton 2003; Thorup 2006), their physiological and behavioral adaptations possibly allow them to cope with a higher diversity of climate regimes than non-migratory ones (Klaassen 1996; Berthold et al. 2003; Thorup 2006; Salewski and Bruderer 2007).

2.3.2. Ecological specialization, families and diet habits

The second prediction of the resource-use hypothesis considers differences in the distribution of resources among the taxa due to their adaptations to diverse environments.

Table 2. Observed and simulated BSI values for non-passerine bird.

BSI	%	Monte Carlo Analysis			
		Mean %	Std.dev	Range	*p*
1	38.70	22.00	0.54	20.00 - 24.00	<0.001
2	27.90	33.00	0.74	30.00 - 36.00	*<0.001*
3	15.30	27.00	0.70	24.00 - 29.00	*<0.001*
4	8.25	13.00	0.48	11.00 - 15.00	*<0.001*
5	4.18	4.00	0.29	3.00 - 5.10	0.419
6	3.14	0.80	0.14	0.32 - 1.40	<0.001
7	1.11	0.10	0.05	0.00 - 0.40	<0.001
8	0.89	0.01	0.02	0.00 - 0.11	<0.001
9	0.51	0.00	0.00	0.00 - 0.05	<0.001
10	0.03	0.00	0.00	0.00 - 0.00	1.000

Frequencies of non-passerine bird species in each BSI and comparison with 10000 Monte Carlo simulations. %, Proportion of the total number of species (3951); *p*, probability of species in the simulations being greater than or equal to (plain) or lower than or equal to (italics) the observed proportion. Further information and details about results and data see also Supplementary file 1 for non-migratory and migratory birds and Supplementary file 2 for dietary groups.

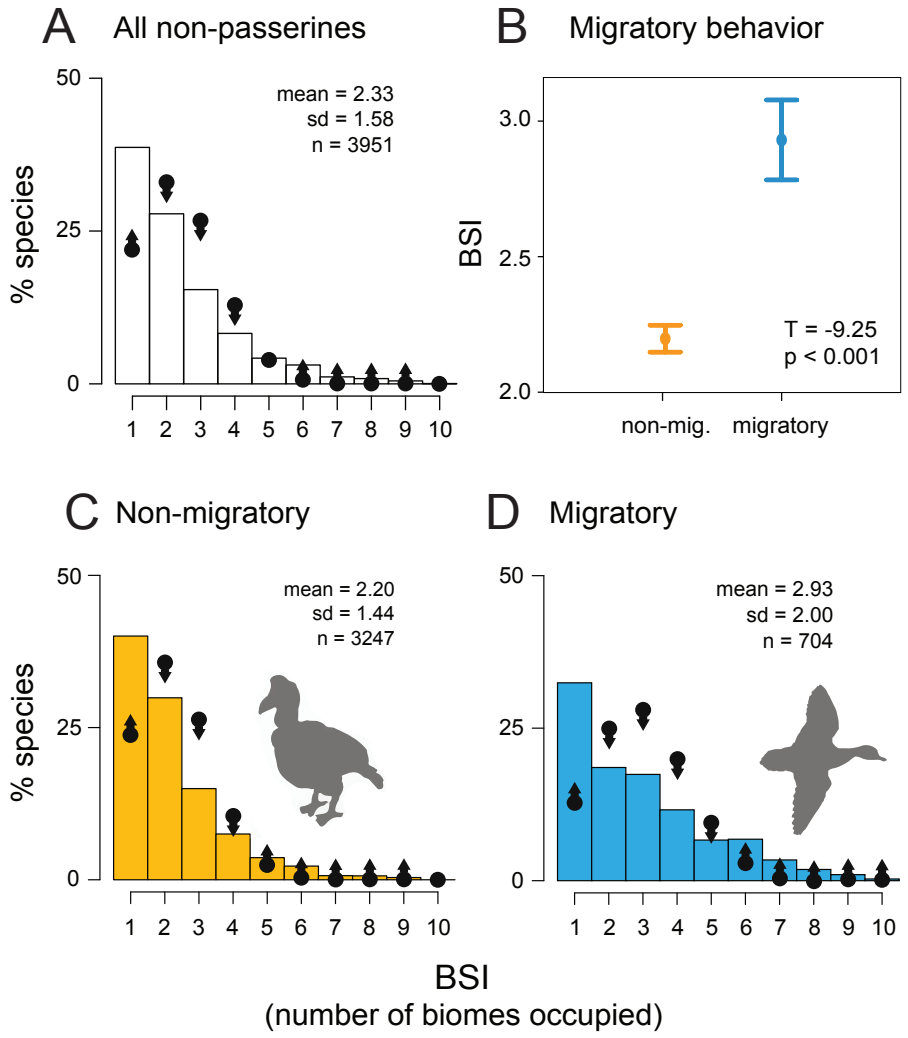


Figure 1. Biome specialization of non-passerine birds (*A*); bars represent the observed distribution of BSI and dots show the average percentage of species from 10,000 Monte Carlo simulations (Table 2); significant differences between observed and simulated values ($p < 0.05$) are shown with arrows. (*B*) Differences in biome specialization between migratory and non-migratory species. Detailed distributions of observed and simulated BSI are also shown for non-migratory (*C*) and migratory (*D*). More details in Table S1 and Supplementary Figures (Appendix 2.8).

Our results at the family level show substantial differences among families, indeed (Fig. 2, Fig.S1). Nevertheless, it is clear that there is still a much higher prevalence of specialist species than expected for the majority of the bird families (84%, Fig. 2) independently of their migratory status (Fig. 2, Appendix 2.8.3). Additionally, the patterns at the family level for generalist species were also similar to the general pattern, although they were less conspicuous (Fig. 2) probably associated to the lower species numbers of extreme generalists.

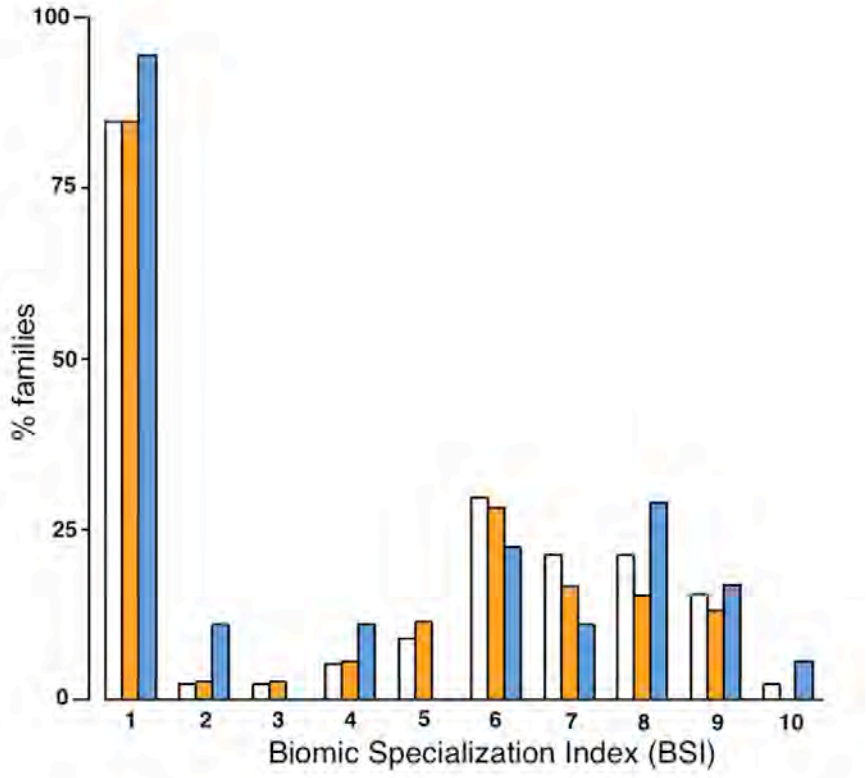


Figure 2. Biome specialization across non-passerine families. Frequencies of families with significantly higher proportion of species in a given BSI category than expected by chance. Only families with more than 10 species were analyzed (see Methods). Analyses were repeated for all the species (white, 50 families), excluding migratory species (orange, 44 families) and excluding non-migratory species (blue, 17 families). For additional information about results and data for each family see also supplementary Figures S1 to S4 (Appendix 2.8).

The three dietary groups showed striking similarities to the general pattern seen before, with prevalence of specialist species, underrepresentation of moderate generalists and overrepresentation of extreme generalist species (Fig. 3A-C). In any case, herbivores are significantly more biome-specialized than faunivores, which appear displaced towards higher BSI values, and omnivores are in an intermediate position (Fig. 3D).

Higher BSI values in faunivores (Fig. 3B) suggest that they can find their main food source in environments that differ vastly in climate, since they are not usually restricted to a particular prey species (Carbone et al. 1999; Carbone et al. 2007; Ingram et al. 2009; Sibly et al. 2012; Price et al. 2012). Additionally, many faunivorous bird lineages are adapted to aquatic environments (Fig. 2, Appendix 2.8), in these habitats they may find a great variety of resources such as fish or invertebrates

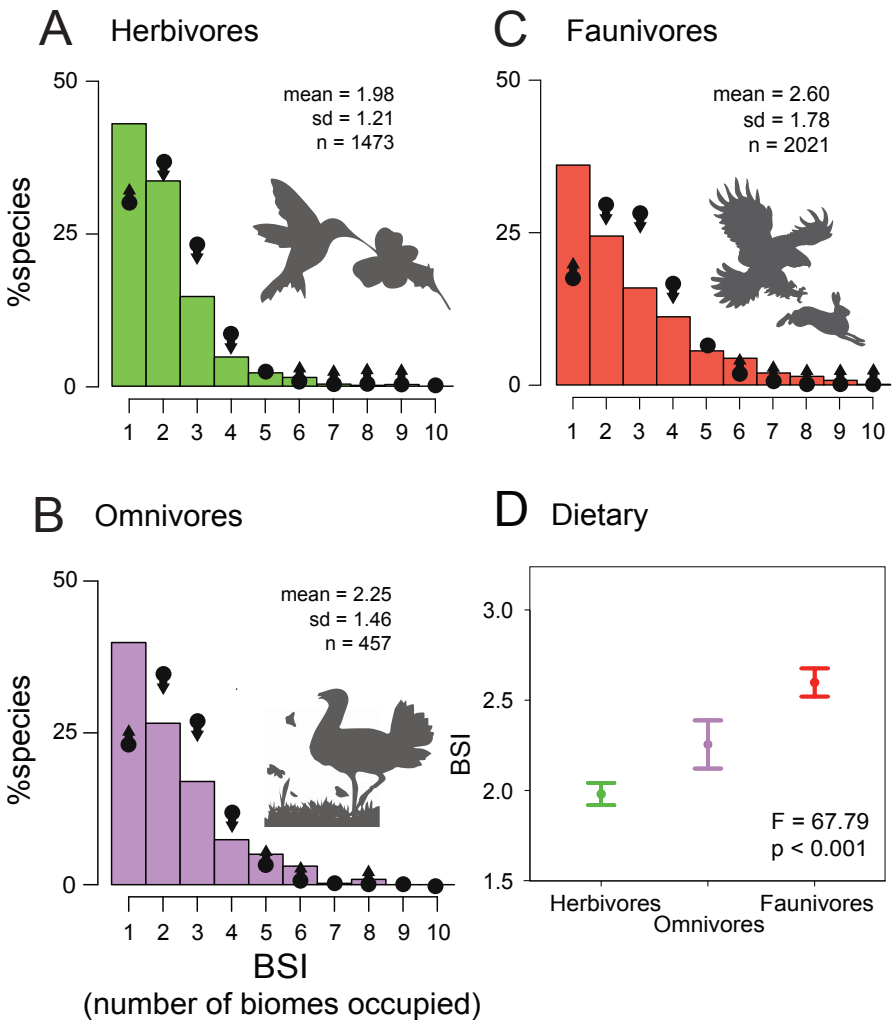


Figure 3. Biome specialization of non-passerine birds with different diets. Detailed distributions of observed and simulated BSI for herbivorous (*A*), faunivorous (*B*) and omnivorous (*C*) species. Bars represent the observed distribution of BSI; dots show the average percentage of species from 10,000 Monte Carlo simulations; and significant differences between observed and simulated values ($p < 0.05$) are shown with arrows. (*D*) Differences in biome specialization between three dietary groups. Further information and details about results and data see also Table S2 (Appendix 2).

(Cody 1973; Ballance et al. 1997; Van Tuinen et al. 2001; Steinmetz et al. 2003). Since these environments are often transversal to terrestrial biomes, these groups have been able to develop ecological and reproductive strategies in specialized niches, but with a lower dependency on terrestrial habitats and their resources, which allowed them to reach broad geographical distributions (Proches 2001; Buckton and Ormerod 2002; Steinmetz et al. 2003; Davies et al. 2010).

The clearer dominance of specialists among herbivorous species (Fig. 3A) could be related to morphological and physiological adaptations which allow them to exploit

food resources from plants restricted to particular biomes (Gill 2007; Wheelwright 1985). Additionally, co-evolutionary relationships between reproductive strategies of plants and numerous herbivore birds (e.g. hummingbirds, parrots and toucans), which exert a positive selection for both parts (Wheelwright 1985; Flörchinger et al. 2010; Stiles 1981; Gill 2007), generate more opportunities for biome specialization in herbivore species. As an effect of the stability of this co-evolution process and the associated smaller geographic dispersions, the generation of diversity through niche subdivision may be facilitated (Price et al. 2012).

The intermediate position of omnivore (Fig. 3C) species can be considered as result of a compromise between the environmental restrictions associated to plant feeding and the versatility provided by facultative faunivory. Due to its ecological plasticity, omnivory appears as an important strategy to survive during seasons of limited food availability or times of environmental perturbation, which allows omnivorous species, inhabit different environments (Price et al. 2012; Vandermeer 2006).

2.3.3. Avian specialization across different biomes

During periods of climate shift, some biomes undergo contraction and fragmentation processes, which promote speciation and extinction. Because not all the biomes respond equally to such shifts, the resource-use hypothesis predicts differential evolutionary processes in different biomes, which in turn will render different proportions of biome specialists within them (Vrba 1992). Biomes located at the extremes of the global climatic gradient such as the equatorial rainforest (I), subtropical desert (III), steppe (VII) and tundra (IX) are more prone to fragmentation due to global climatic changes and, therefore, should be characterized by a clear overrepresentation of biome specialists.

Monte Carlo analysis revealed significantly high biome specialization in these biomes when all non-passerine birds were analyzed as a whole (Table 3, Fig. 4). The results for families (Fig. 2) were also coherent with the general pattern: most families showed overrepresentation of specialists in the rainforest, and substantial proportions of the families also presented more biome specialists than expected by chance in desert, steppe and tundra (Fig. 4). This distribution of specialization within clades is consistent with the third prediction. Interestingly, the rainforest showed the highest incidence (>60%) of families with statistically significant overrepresentation of specialists in a single biome. This is a biome with a much older origin and climatically more stable

than the desert, steppe and tundra, which appeared during the last 5 million years (Potts and Behrensmeyer 1992).

Interestingly, two biomes that were not included in the prediction showed higher prevalence of specialist species than expected. This is the case for the tropical deciduous woodland (II) in both the complete analysis (Table 3) and in a substantial part of non-passerine families (Fig. 4 and Fig. 2). Such pattern has already been reported in previous works with mammals (Hernández Fernández and Vrba 2005; Cantalapiedra et al. 2011; Moreno Bofarull et al. 2008). Though this biome does not represent a climatic extreme, its historical dynamics in close association with the rainforest fluctuations and geological processes in African and American tropics (Williams et al. 1999; Hoorn et al. 2010). The heterogeneous mosaic structure of the deciduous woodlands (Williams and Pearson 1997; Hoorn et al. 2010; Jetz and Fine 2012) may have favored the survival of specialists in temporal refugia during climatic shifts (Haffer 1969; Mayr and O´hara 1986; Haffer 1997; Ribas et al. 2011). Also, the

Table 3. Observed and simulated distribution of stenobiomic non-passerine bird species (BSI = 1) across biomes.

Biome	Non-passerine birds			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	Std.dv	Range	*p*
I	1982	672	33.91	11.30	0.65	8.63 - 13.80	<0.001
II	1940	291	15.00	11.10	0.65	8.40 - 13.60	<0.001
II/III	926	49	5.21	7.38	0.83	4.75 - 10.70	*0.003*
III	401	45	11.22	6.28	1.20	2.24 - 11.20	<0.001
IV	515	21	4.08	6.51	1.10	3.11 - 11.10	*0.005*
V	1360	145	10.66	8.62	0.72	5.81 - 11.40	0.001
VI	640	35	5.47	6.73	0.97	3.59 - 10.90	*0.093*
VII	606	118	19.47	6.69	0.98	3.30 - 11.10	<0.001
VIII	569	40	7.08	6.56	1.00	3.01 - 10.40	0.371
IX	263	112	42.59	6.04	1.50	1.52 - 11.40	<0.001

sp., number of species; % proportion of species with BSI = 1 in relation to total number of species in each biome; *p*, probability in each biome of the proportion of species with BSI = 1 being greater than or equal to (plain) or lower than or equal to (*italics*) the observed proportion.

subtropical evergreen forest (V) appears as an important environment for specialist species in around a quarter of the non-passerine families (Fig. 4). This biome extends through lowlands in humid subtropical areas, but it is also associated to montane environments in tropical regions (Still et al. 1999; Hewitt 2000). Therefore, historical climate dynamics along elevation gradients, which are responsible for multiple successive vicariance events, have created new opportunities for speciation stemming from isolated populations (Roy 1997; Bonaccorso and Guayasamin 2013; Quintero et al. 2013). Such processes have significantly contributed to the high richness and endemism in most tropical mountain areas (Fjeldså and Lovett 1997; Kattan and Franco 2004; Kozak and Wiens 2007).

When the migratory status is taken into account, differences between migratory and non-migratory species are observed (Fig. 4 and Fig. 2, Appendix 2.8). While non-migratory species showed marked overspecialization in equatorial rainforest (I), migratory specialist species are much more abundant in tundra (IX) and subtropical desert (III) than expected by chance (Fig. 4). While the high productivity and habitat heterogeneity of the rainforest facilitates reproductive isolation and speciation in many sedentary clades (Ribas et al. 2011; Jetz and Fine 2012), thriving in the tundra and the desert requires a high degree of specialization in morphology, physiology and behavior.

Therefore, in such scenario, long distance migratory behavior could have worked as an adaptation of species to avoid seasonal shortage of food resources while preserving their reproductive niche (Sandercock et al. 2005; Jetz et al. 2008; García-Peña et al. 2009).

In the case of steppe (VII) and subtropical evergreen forest (V) inhabitants, the overrepresentation of specialists is found in substantially more families for non-migratory species than in migratory ones (Fig. 4). Sedentary species in these biomes are usually associated to tropical montane environments, which are particularly affected by climatic oscillations and have favored vicariance processes in many populations of tropical birds (Wiens and Rotenberry 1980; Fjeldså 1992; Fjeldså and Lovett 1997; Weir 2006; Bonaccorso and Guayasamin 2013) as commented before. Finally, there were higher percentages of families with more biome specialists than expected in migratory species of the taiga (VIII) and the savanna (II/III) than in the non-migratory ones (Fig. 4). This is probably related to the intense seasonality of these environments, following the resources rationale explained above for the tundra and the desert.

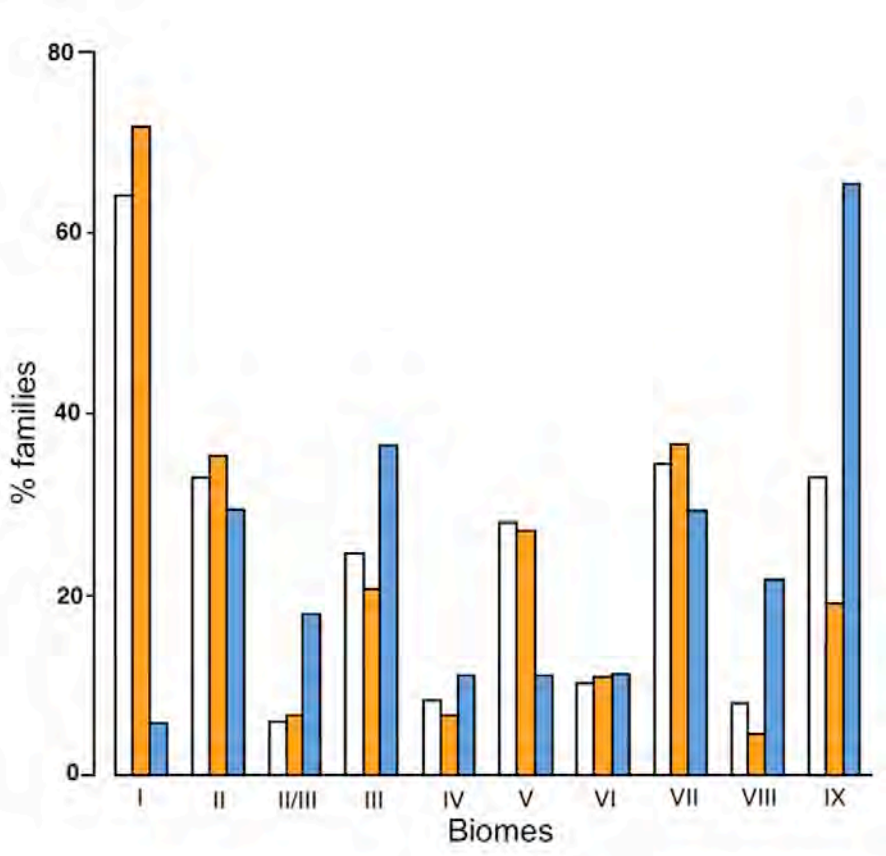


Figure 4. Biome specialization across non-passerine families and biomes. Frequencies of families presenting a significantly higher proportion of specialist species in a given biome when compared to simulations. Only families with more than 10 species were analyzed (see Methods). Analyses were repeated for all the species (white, 50 families), excluding migratory species (orange, 44 families) and excluding non-migratory species (blue, 17 families). Results and data for each family derived from Supplementary information of Fig.2 (Figures S1 to S4 in Appendix 2.8).

2.5. CONCLUSIONS

The resource-use hypothesis suggests that a key to understand patterns of diversity is to be found in historical processes: the turnover (speciation, extinction) of clades is related to abiotic changes. Our results present important evidences of the relationship between these processes and the evolution of non-passerine birds, in agreement with the predictions of the hypothesis. We found high frequency of species restricted to a single biome as a consequence of high speciation rates in biomes historically subjected to successive expansion-contraction-fragmentation processes during periods of climate change. This general pattern is maintained independently of the migratory behavior, although migratory species tend to be less specialized than non-migratory ones. Biome specialists are more abundant in herbivorous taxa than in omnivores or faunivores.

Exceptions to the predictions of the resource-use hypothesis seem to be associated to montane biogeography and biome heterogeneity. Globally, the present contribution highlights the apparent universality of the resource-use hypothesis for terrestrial vertebrates, which for the first time has been tested using a non-mammalian clade.

2.6. AKNOWLEDGEMENTS

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2.7. LITERATURE CITED

Araújo MB, Ferri-Yáñez F, Bozinovic F, Marquet PA, Valladares F, Chown SL (2013) Heat freezes niche evolution. *Ecol Lett* 16 (9):1206-1219.

Ballance LT, Pitman RL, Reilly SB (1997) Seabird Community Structure Along a Productivity Gradient: Importance of Competition and Energetic Constraint. *Ecology* 78 (5):1502-1518

Barnosky A (2001) Distinguishing the effects of the red queen and court jester on Miocene mammal evolution in the Northern Rocky Mountains. *J Vertebr Paleontol* 21:172 - 185

Bell CP (2000) Process in the evolution of bird migration and pattern in avian ecogeography. *J Avian Biol* 31:258-265

Benton J (2009) The Red Queen and the Court Jester: species diversity and the role of biotic and abiotic factors through time. *Science* 323:728 - 732

Berthold P, Gwinner E, Sonnenshein E (2003) *Avian Migration*. Springer, Berlin, New York

Bonaccorso E, Guayasamin JM (2013) On the Origin of Pantepui montane biotas: A Perspective Based on the Phylogeny of *Aulacorhynchus* toucanets. *PLoS ONE* 8(6): e67321

Bromham L, Cardillo M (2003) Testing the link between the latitudinal gradient in species richness and rates of molecular evolution. *J Evol Biol* 16 (2):200-207

Buckley LB, Davies TJ, Ackerly DD, Kraft NJ, Harrison SP, Anacker BL, Cornell HV, Damschen E, Grytnes J-A, Hawkins B, McCain CM, Stephens PR, J.J. W (2010) Phylogeny, niche conservatism and the latitudinal diversity gredient in mammals. *Proc R Soc Lond B* 277:2131-2138

Buckley LB, Jetz W (2007) Environmental and historical constraints on global patterns of amphibian richness. *Proc R Soc Lond B* 274 (1614):1167-1173.

Buckton ST, Ormerod SJ (2002) Global patterns of diversity among the specialist birds of riverine landscapes. *Freshw Biol* 47:695-709

Cantalapiedra JL, Hernández Fernández M, Morales J (2011) Biomic specialization and speciation rates in ruminants (Cetartiodactyla, Mammalia): a test of the resourse-use hypothesis at global scale. *PLoS ONE* 6 (12): e28749

Carbone C, Mace GM, Roberts SC, Macdonald DW (1999) Energetic constraints on the diet of terrestrial carnivores. *Nature* 402:286-288

Carbone C, Teacher A, Rowcliffe JM (2007) The Costs of Carnivory. *PLoS Biol* 5 (2):e22.

Cardillo M (1999) Latitude and rates of diversification in birds and butterflies. *Proc R Soc Lond B* 266 (1425):1221-1225.

Cardillo M, Orme CDL, Owens IPF (2005) Testing for latitudinal bias in diversification rates: an example using New Wold Birds. *Ecology* 86 (9):2278-2287

Cody M (1973) Coexistence, Coevolution and Convergent Evolution in Seabirds Communities. *Ecology* 54:31-44

Cracraft J (1973) Continental Drift, Paleoclimatology, and the evolution and Biogeography of Birds. *J Zool* 169 (455-543)

Davies RG, Irlich UM, Chown S, Gaston KJ (2010) Ambient, productive and wind energy, and ocean extent predict global species richness of procellariiform seabirds. *Glob Ecol Biogeogr* 19:98-110

Del Hoyo J, Elliott A, Sargatal J (1992) *Ostrich to Ducks. Handbook of the Birds of the World*, vol 1. Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (1994) *New World Vultures to Guineafowl. Handbook of the Birds of the World*, vol 2. . Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (1996) *Hoatzin to Auks. Handbook of the Birds of the World*, vol 3. Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (1997) *Sandgrouse to Cuckoos. Handbook of the Birds of the World*, vol 4. Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (1999) *Barn-Owls to Hummingbirds. Handbook of the Birds of the World*, vol 5. Lynx edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (2001) *Mousebirds to Hornbills. Handbook of the Birds of the World*, vol 6. Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (2002) *Jacamars to Woodpeckers. Handbook of the Birds of the World*, vol 7. Lynx Edicions, Barcelona

Diniz-Filho JAF, Rangel TFVB, Bini LM, Hawkins BA (2007) Macroevolutionary dynamics in environmental space and the latitudinal diversity gradient in New World birds. *Proc R Soc Lond B* 274:43-52

Douglas ME, Douglas MR, Schuett W, Porras LW (2006) Evolution of rattlesnakes (Viperidae;*Crotalus*) in the warm deserts of western North America shaped by Neogene vicariance and Quaternary climate change. *Mol Ecol* 15:3353-3374

Finarelli JA, Badgley C (2010) Diversity dynamics of Miocene mammals in relation to the history of tectonism and climate. *Proc R Soc Lond B* 277 (1694):2721-2726

Fjeldså J (1992) Biogeographic patterns and evolution of the avifauna of relict high-altitude woodlands of the Andes. *Steenstrupia* 18:9-62

Fjeldså J (2012) Diversification of the neotropical avifauna: disentangling the geographical patterns of persisting ancient taxa and phylogenetic expansions. *Ornitol Neotrop* 23:13-27

Fjeldså J, Lovett JC (1997) Geographical patterns of old and young species in African forest biota: the significance of specific montane areas as evolutionary centres. *Biodivers Conserv* 6:325-346

Flörchinger M, Braun J, Böhning-Gaese K, Schaefer HM (2010) Fruit size, crop mass, and plant height explain differential fruit choice of primates and birds. *Oecologia* 164 (1):151-161.

Francis AP, Currie DJ (2003) A globally consistent richness–climate relationship for Angiosperms. *Am Nat* 161 (4):523-536

García-Peña GE, Thomas GH, Reynolds JD, Székely T (2009) Breeding systems, climate, and the evolution of migration in shorebirds. *Behav Ecol* 20 (5):1026-1033.

Gaston KJ, Davies R, Gascoigne C, Williamson M (2004) The structure of global species–range size distributions: raptors y owls. *Glob Ecol Biogeogr* 14 (1):67-76

Gill FB (2007) *Ornithology*. 3 edn. WH Freeman, New York

Gómez Cano AR, Cantalapiedra JL, Mesa A, Moreno Bofarull A, Hernández Fernández M (2013) Global climate changes drive ecological specialization of mammal faunas: trends in rodent assemblages from the Iberian Plio-Pleistocene. *BMC Evol Biol* 13 (1):94

Haffer J (1969) Speciation in Amazonian Forest Birds. *Science* 165 (3889):131-137

Haffer J (1997) Alternative models of vertebrate speciation in Amazonia: an overview. *Biodivers Conserv* 6:451-476

Hawkins BA, Diniz-Filho JAF, Jaramillo CA, Soeller SA (2006) Post-Eocene climate change, niche conservatism, and the latitudinal diversity gradient of New World birds. *J Biogeogr* 33:770-780

Hawkins BA, Diniz-Filho JAF, Jaramillo CA, Soeller SA (2007) Climate, Niche Conservatism, and the Global Bird Diversity Gradient. *Am Nat* 170 (Supplement):S16-S27

Hawkins BA, McCain CM, Davies TJ, Buckley LB, Anacker BL, Cornell HV, Damschen EI, Grytnes J-A, Harrison S, Holt RD, Kraft NJB, Stephens PR (2012) Different evolutionary histories underlie congruent species richness gradients of birds and mammals. *J Biogeogr* 39:825-841

Hernández Fernández M (2001) Bioclimatic discriminant capacity of terrestrial mammal faunas. *Glob Ecol Biogeogr* 10:189 - 204

Hernández Fernández M, Vrba ES (2005) Macroevolutionary processes and biomic specialization: testing the resource-use hypothesis. *Evol Ecol* 19:199-119Hewitt G (2000) The genetic legacy of the Quaternary ice ages. *Nature* 405:907-913

Hoorn C, Wesselingh FP, ter Steege H, Bermudez MA, Mora A, Sevink J, Sanmartín I, Sánchez-Meseguer A, Anderson CL, Figueiredo JP, Jaramillo CA, Riff D, Negri FR, Hooghiemstra H, Lundberg J, Stadler T, Särkinen T, Antonelli A (2010) Amazonia Through Time: Andean Uplift, Climate Change, Landscape Evolution, and Biodiversity. *Science* 330 (6006):927-931.

Howard R, Moore A (2013) *The Howard and Moore Complete Checklist of the Birds of the World*, vol 1: Non-passerines.

Ingram T, Harmon LJ, Shurin JB (2009) Niche Evolution, Trophic Structure, and Species Turnover in Model Food Webs. *Am Nat* 174 (1)

International. B (2013) *Species Data Zone*. http://www.birdlife.org/datazone.

IUCN (2012) The IUCN *Red List of Threatened Species.* Version 2012.1. http://www.iucnredlist.org/. Accessed Downloaded on 02 July 2013.

Jetz W, Fine PVA (2012) Global gradients in vertebrate diversity predicted by historical area-productivity dynamics and contemporary environment. *PLoS Biol* 10 (3):e1001292.

Jetz W, Sekercioglu CH, Bohning-Gaese K (2008) The Worldwide Variation in Avian Clutch Size across Species and Space. *PLoS Biol* 6 (12):2650-2657

Kattan GH, Franco P (2004) Bird diversity along elevational gradients in the Andes of Colombia: area and mass effects. *Glob Ecol Biogeogr* 13:451-458

Kennedy JD, Wang Z, Weir JT, Rahbek C, Fjeldså J, Price T (2014) Into and out of the tropics: the generation of the latitudinal gradient among New World passerine birds. *J Biogeogr*:1-12.

Klaassen M (1996) Metabolic constraints on long-distance migration in birds. *J Exp Biol* 199:57-64

Kozak KH, Wiens JJ (2007) Climatic zonation drives latitudinal variation in speciation mechanisms. *Proc R Soc Lond B* 274 (1628):2995-3003.

Lister AM (2004) The impact of Quaternary Ice Ages on mammalian evolution. *Philos Trans R Soc B* 359:221-241

Mayr E, O´hara RJ (1986) The biogeographic evidence supporting the Pleistocene forest refuge hypothesis. *Evolution* 40:55-67

Moreno Bofarull A, Arias Royo A, Hernández Fernández M, Ortiz-Juareguizar E, Morales J (2008) Influence of continental history on the ecological specialization and macroevolutionary procesess in the mammalian assemblage of South America: Differences between small and large mammals. *BMC Evol Biol* 8 (97):1-18

Newton I (2003) *The speciation and biogeography of birds*. Academic Press, London & San Diego

Penny D, Phillips MJ (2004) The rise of birds and mammals: are microevolutionary processes sufficient for macroevolution? *Trends Ecol Evol* 19 (10):1-7

Potts R, Behrensmeyer A (1992) Late Cenozoic terrestrial ecosystems. *Terrestrial Ecosystems trough Time*: 419 - 541

Price S, Hopkins S, S.B, Smith K, Roth L (2012) Tempo of trophic evolution and its impact on mammal diversification. *Proc Natl Acad Sci USA* 109 (18):7008-7012

Proches S (2001) Back to the sea: secondary marine organisms from a biogeographical perspective. *Biol J Linn Soc* 74:197-203

Quintero E, Ribas CC, Cracraft J (2013) The Andean *Hapalopsittaca* parrots (Psittacidae, Aves): an example of montane-tropical lowland vicariance. *Zool Scr* 42 (1):28-43.

R Development Core Team (2013) *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. Foundation for Statistical Computing, Vienna, Austria

Ramos Pereira ML, Palmeirim JM (2013) Latitudinal diversity gradients in New World Bats: Are they a consequence of Niche conservatism? *PLoS ONE* 8 (7):e69245

Ribas CC, Aleixo A, Nogueira ACR, Miyaki CY, Cracraft J (2011) A palaeobiogeographic model for biotic diversification within Amazonia over the past three million years. *Proc R Soc Lond B*:1-9

Roelants K, Gower DJ, Wilkinson M, Loader SP, Biju SD, Guillaume K, Moriau L, Bossuyt F (2007) Global patterns of diversification in the history of modern amphibians. *Proc Natl Acad Sci USA* 104 (3):887-892

Roy MS (1997) Recent diversification in African greenbuls (Pycnonotidae: *Andropadus*) supports a montane speciation model. *Proc R Soc Lond B* 264:1337-1344

Salewski V, Bruderer B (2007) The evolution of bird migration, a synthesis. *Naturwissenschaften* 94:268-279

Sandercock BK, Martin K, Hannon SJ (2005) Life history strategies in extreme enviroments: Comparative demography of Arctic and Alpine Ptarmigan. *Ecology* 86 (8)

Sibly RM, Witt CC, Wright NA, Venditti C, Jetz W, Brown JH (2012) Energetics, lifestyle, and reproduction in birds. *Proc Natl Acad Sci USA* 109 (27):10937-10941

Steinmetz J, Kohler SL, Soluk DL (2003) Birds are overlooked top predators in aquatic food webs. *Ecology* 84 (5):1324-1328

Stiles G (1981) Geographical aspects of Bird-Flower coevolution, with particular reference to Central America. *Ann Mo Bot Gard* 68 (2):323-351

Still CJ, Foster PN, Schneider SH (1999) Simulating the effects of climate change on tropical montane cloud forests. *Nature* 398 (6728):608-610

Thorup K (2006) Does the migration constrain dispersal and range sizes of migratory birds? *J Biogeogr* 33:1166-1171

Van Tuinen M, Butvill DB, Kirsch JA, Hedges B (2001) Convergence and divergence in the evolution of aquatic birds. *Proc R Soc Lond B* 268:1345-1350

Vandermeer J (2006) Omnivory and the stability of food webs. *J Theor Biol* 238:497-504

Voelker G, Outlaw RK, Bowie RCK (2010) Pliocene forest dynamics as a primary driver of African bird speciation. *Glob Ecol Biogeogr* 19:111-121

Vrba ES (1980) Evolution, species and fossils: how does life evolve? *S Afr J Sci* 76:61-84

Vrba ES (1987) Ecology in relation to speciation rates; some case histories of Miocene-Recent mammal Clades. *Evol Ecol* 1:283-300

Vrba ES (1992) Mammals as a key to evolutionary theory. *J Mammal* 73:1-28

Vrba ES (1995) On the connections between paleoclimate and evolution. In: Vrba ES, Denton GH, Partridge TC, Burckle LH (eds) *Paleoclimate and Evolution, with Emphasis of Human Origins*. Yale University Press, New Haven, USA, pp 24-45

Walter H (1970) *Vegetationszonen und klima*. Eugen Ulmer, Stuttgart

Weir J (2006) Divergent timing and Patterns of species accumulation in lowland and highland Neotropical Birds. *Evolution* 60 (4):842-855

Weir JT, Schluter D (2004) Ice sheets promote speciation in boreal birds. *Proc R Soc Lond B* 271 (1551):1881-1887.

Wheelwright NT (1985) Fruit size, gape width, and the diets of fruit-eating birds. *Ecology* 66 (3):808-818

Wiens JA, Rotenberry JT (1980) Patterns of Morphology and Ecology in Grassland and Shrubsteppe Bird Populations. *Ecol Monogr* 50 (3):287-308

Wiens JJ, Ackerly DD, Allen AP, Anacker BL, Buckley LB, Cornell HV, Damschen EI, Davies TJ, Grytnes J-A, Harrison SP, Hawkins BA, Holt RD, McCain CM, Stephens PR (2010) Niche conservatism as an emerging principle in ecology and conservation biology. *Ecol Lett* 13:1310-1324

Williams PH, de Klerk HM, Crowe TM (1999) Interpreting biogeographical boundaries among Afrotropical birds: spatial patterns in richness gradients and species replacement. *J Biogeogr* 26:459-474

Williams SE, Pearson RG (1997) Historical rainforest contraction, localized extinctions and patterns of vertebrate endemism in the rainforest of Australia′s wet tropics. *Proc R Soc Lond B* 264:709-716

Willig MR, Kaufman DM, Stevens RD (2003) Latitudinal Gradients of Biodiversity: Pattern, Process, Scale, and Synthesis. *Annu Rev Ecol Evol Syst* 34:273-309

Worgester R, Ydenberg R (2008) Cross-continental patterns in the timing of southward Peregrine Falcon migration in North America. *J Raptor Res* 42 (1):13-19

2.8. Appendix

Appendix 2.8.1 - Table S1. Observed and simulated BSI values for non-migratory and migratory species.

BSI	Non Migratory %	Monte Carlo Analysis			
		Mean %	Std.dv.	Range	*p*
1	40.00	24.00	0.60	22.00 - 26.00	<0.001
2	30.00	36.00	0.85	33.00 - 39.00	*<0.001*
3	14.90	26.00	0.75	24.00 - 29.00	*<0.001*
4	7.51	11.00	0.49	8.90 - 12.00	*<0.001*
5	3.63	2.50	0.26	1.50 - 3.80	<0.001
6	2.28	0.36	0.11	0.07 - 0.82	<0.001
7	0.68	0.03	0.03	0.00 - 0.20	<0.001
8	0.65	0.00	0.01	0.00 - 0.07	<0.001
9	0.37	0.00	0.00	0.00 - 0.03	<0.001
10	0.00	0.00	0.00	0.00 - 0.00	1.000
BSI	**Migratory %**	**Monte Carlo Analysis**			
		Mean %	**Std.dv.**	**Range**	***p***
1	32.50	13.00	1.10	9.20 - 17.00	<0.001
2	18.30	25.00	1.50	20.00 - 30.00	*<0.001*
3	17.30	28.00	1.70	23.00 - 35.00	*<0.001*
4	11.60	20.00	1.40	16.00 - 25.00	*<0.001*
5	6.68	9.70	1.00	5.90 - 14.00	*0.001*
6	7.10	3.20	0.62	1.20 - 5.70	<0.001
7	3.12	0.69	0.31	0.00 - 2.10	<0.001
8	1.99	0.10	0.12	0.00 - 0.74	<0.001
9	1.14	0.01	0.03	0.00 - 0.30	<0.001
10	0.14	0.00	0.01	0.00 - 0.15	<0.001

Proportion of non-passerine bird species in each BSI category: non-migratory (n= 3247) and migratory (n = 704), and comparison with 10,000 Monte Carlo simulations. *p*, probability of species in the simulations being greater than or equal to (plain) or lower than or equal to (italics) the observed proportion.

Appendix 2.8.2. - Table S2. Observed and simulated BSI values for different dietary groups

BSI	Herbivores %	Monte Carlo Analysis			
		Mean %	Std.dv.	Range	*p*
1	42.60	30.00	0.96	25.00 - 33.00	<0.001
2	33.70	37.00	1.30	32.00 - 42.00	*0.004*
3	14.60	23.00	1.10	20.00 - 28.00	*<0.001*
4	4.68	8.30	0.66	6.10 - 11.00	*<0.001*
5	2.17	1.80	0.34	0.67 - 3.10	0.123
6	1.49	0.23	0.13	0.00 - 0.89	<0.001
7	0.34	0.02	0.04	0.00 - 0.23	<0.001
8	0.14	0.00	0.01	0.00 - 0.15	<0.001
9	0.27	0.00	0.00	0.00 - 0.07	<0.001
10	0.00	0.00	0.00	0.00 - 0.00	1.000
BSI	**Omnivores %**	**Monte Carlo Analysis**			
		Mean %	**Std.dv.**	**Range**	***P***
1	40.00	23.00	1.60	17.00 - 29.00	<0.001
2	26.50	35.00	2.30	26.00 - 43.00	*<0.001*
3	16.80	27.00	2.00	20.00 - 35.00	*<0.001*
4	7.44	12.00	1.40	6.60 - 17.00	*<0.001*
5	5.03	3.20	0.78	0.90 - 6.80	0.013
6	3.06	0.51	0.33	0.00 - 2.10	<0.001
7	0.22	0.05	0.11	0.00 - 0.71	0.243
8	0.88	0.00	0.03	0.00 - 0.46	<0.001
9	0.00	0.00	0.00	0.00 - 0.23	0.999
10	0.00	0.00	0.00	0.00 - 0.00	1.000
BSI	**Faunivores %**	**Monte Carlo Analysis**			
		Mean %	**Std.dv.**	**Range**	***P***
1	35.40	17.00	0.70	15.00 - 20.00	<0.001
2	24.00	30.00	0.96	26.00 - 33.00	*<0.001*
3	15.60	28.00	1.00	24.00 - 32.00	*<0.001*
4	11.00	17.00	0.77	14.00 - 20.00	*<0.001*
5	5.49	6.30	0.50	4.60 - 8.20	*0.050*
6	4.30	1.60	0.27	0.72 - 2.60	<0.001
7	1.93	0.26	0.12	0.00 - 0.78	<0.001
8	1.39	0.03	0.04	0.00 - 0.21	<0.001
9	0.74	0.00	0.01	0.00 - 0.10	<0.001
10	0.10	0.00	0.00	0.00 - 0.05	<0.001

Proportion of non-passerine bird species in each BSI category: Herbivores (n= 1473), Omnivores (n = 457) and Faunivores (n = 2021) and comparison with 10,000 Monte Carlo simulations.*p*, probability of species in the simulations being greater than or equal to (plain) or lower than or equal to (i*talics*) the observed proportion.

Appendix 2.8.3. Supplementary data of Figure 2 (Fig. S1 from A to Q) – All species (Fam. >10 spp)

BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	48.90	32.00	5.50	10 - 52	<0.001
2	29.80	38.00	7.50	11 - 67	0.149
3	10.60	22.00	5.80	2.3 - 54	0.017
4	8.51	6.40	3.40	0 - 25	0.375
5	2.13	0.90	1.40	0 - 10	0.484
6	0.00	0.05	0.34	0 - 2.6	0.979
7	0.00	0.00	0.05	0 - 2.4	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Tinamidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	25	9	36.00	20.40	6.90	0 - 48	0.008
II	20	3	15.00	16.70	7.60	0 - 50	0.783
II/III	13	3	23.08	13.30	8.90	0 - 53.8	0.079
III	1	0	0.00	9.96	30.00	0 - 100	0.111
IV	1	0	0.00	9.66	30.00	0 - 100	0.107
V	14	2	14.29	13.60	8.60	0 - 57.1	0.402
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	11	6	54.55	12.40	9.40	0 - 54.5	<0.001
VIII	2	0	0.00	9.69	21.00	0 - 100	0.226
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

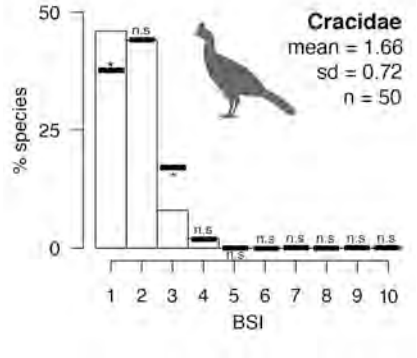
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	25.30	14.00	2.40	5.8 - 22	<0.001
2	24.00	26.00	3.30	14 - 39	0.441
3	19.20	28.00	3.80	14 - 43	0.008
4	12.30	20.00	3.10	8 - 34	0.007
5	10.30	9.20	2.20	2.1 - 17	0.452
6	7.53	2.90	1.30	0 - 9.3	0.001
7	0.00	0.61	0.64	0 - 4.2	0.411
8	1.37	0.08	0.24	0 - 2.1	0.006
9	0.00	0.01	0.07	0 - 0.74	0.992
10	0.00	0.00	0.01	0 - 0.71	1.000

Biome	Anatidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	32	2	6.25	3.96	3.40	0 - 21.9	0.143
II	42	5	11.90	4.32	3.10	0 - 19	0.007
II/III	31	1	3.23	3.93	3.50	0 - 22.6	0.525
III	12	0	0.00	3.43	5.20	0 - 33.3	0.523
IV	45	0	0.00	4.46	3.00	0 - 17.8	<0.001
V	47	0	0.00	4.53	2.90	0 - 17	<0.001
VI	65	4	6.15	5.50	2.70	0 - 16.9	0.398
VII	53	4	7.55	4.83	2.80	0 - 18.9	0.116
VIII	52	5	9.62	4.82	2.90	0 - 19.2	0.038
IX	41	16	39.02	4.30	3.10	0 - 24.4	<0.001

BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	68.40	58.00	7.20	38 - 83	0.039
2	26.30	35.00	10.00	0 - 62	0.234
3	5.26	7.00	5.00	0 - 25	0.273
4	0.00	0.64	1.90	0 - 12	0.893
5	0.00	0.02	0.37	0 - 6.2	0.996
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

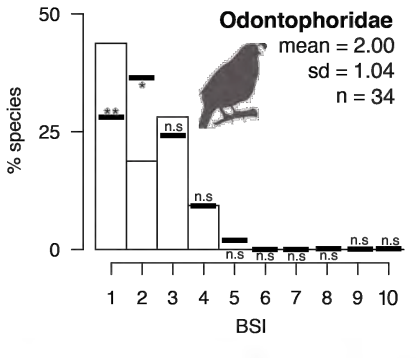
Biome	Megapodiidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	16	12	75.00	56.00	7.10	37.5 - 81.2	0.001
II	5	1	20.00	12.10	13.00	0 - 60	0.101
II/III	1	0	0.00	8.72	28.00	0 - 100	0.096
III	1	0	0.00	9.63	30.00	0 - 100	0.107
IV	1	0	0.00	9.53	29.00	0 - 100	0.105
V	2	0	0.00	9.92	21.00	0 - 100	0.236
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 1A. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species in this plate: Tinamidae, Anatidae and Megapodidae.



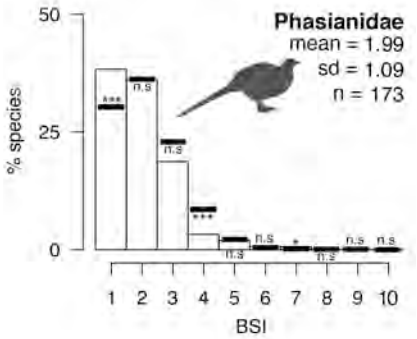
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	46.00	38.00	5.30	17 - 56	0.049
2	44.00	43.00	7.20	17 - 68	0.866
3	8.00	17.00	4.60	2.1 - 37	0.015
4	2.00	1.90	1.80	0 - 10	0.641
5	0.00	0.06	0.36	0 - 4.4	0.973
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Cracidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	33	10	30.30	27.10	5.80	6.06 - 48.5	0.261
II	27	9	33.33	20.10	6.20	0 - 44.4	0.008
II/III	4	0	0.00	10.10	15.00	0 - 75	0.530
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	16	4	25.00	13.40	7.80	0 - 50	0.039
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	3	0	0.00	9.87	17.00	0 - 100	0.366
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	44.10	29	6.30	7.1 - 53	0.005
2	20.60	37	8.60	9.4 - 66	0.030
3	26.5	24	7.00	3.1 - 54	0.511
4	8.82	8.6	4.50	0 - 30	0.890
5	0.00	1.9	2.30	0 - 15	0.535
6	0.00	0.25	0.88	0 - 7.1	0.926
7	0.00	0.016	0.23	0 - 3.7	0.995
8	0.00	0.0013	0.064	0 - 3.2	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

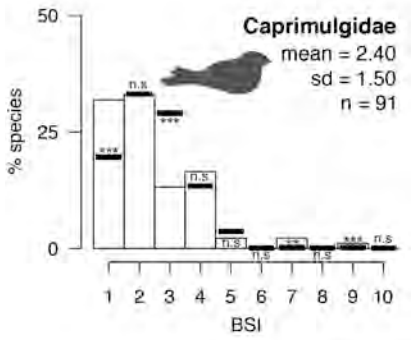
Biome	Odontophoridae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	14	7	50.00	14.30	8.60	0 - 53.8	<0.001
II	14	3	21.43	14.30	8.60	0 - 46.2	0.120
II/III	4	0	0.00	9.34	15.00	0 - 100	0.480
III	3	1	33.33	9.01	16.00	0 - 100	0.023
IV	2	0	0.00	8.71	20.00	0 - 100	0.201
V	17	4	23.53	16.70	8.00	0 - 52.9	0.126
VI	4	0	0.00	9.33	14.00	0 - 75	0.483
VII	3	0	0.00	8.99	16.00	0 - 100	0.329
VIII	7	0	0.00	10.40	11.00	0 - 71.4	<0.001
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	39.30	30.00	2.80	18 - 41	<0.001
2	34.70	36.00	3.80	22 - 49	0.687
3	19.70	23.00	3.20	12 - 34	0.168
4	2.89	9.10	2.10	2.4 - 17	<0.001
5	1.73	2.20	1.10	0 - 7.8	0.444
6	1.16	0.33	0.45	0 - 3.3	0.103
7	0.58	0.03	0.14	0 -1.3	0.047
8	0.00	0.00	0.04	0 - 1.3	0.997
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

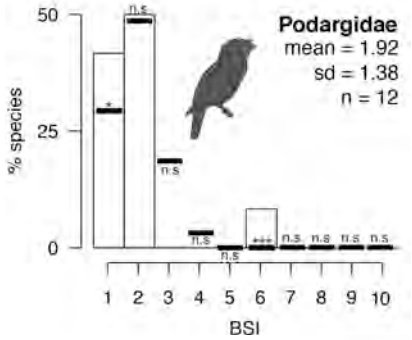
Biome	Phasianidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	46	16	34.78	12.60	4.60	0 - 31.9	<0.001
II	87	21	24.14	18.60	3.70	7.06 - 31.8	0.126
II/III	35	1	2.86	11.50	5.20	0 - 35.3	0.016
III	9	3	33.33	9.65	9.70	0 - 55.6	0.007
IV	14	0	0.00	10.20	7.90	0 - 42.9	<0.001
V	52	5	9.62	13.30	4.50	0 - 28	0.106
VI	36	2	5.56	11.70	5.20	0 - 33.3	0.066
VII	39	16	41.03	11.90	4.90	0 - 30.8	<0.001
VIII	24	3	12.50	10.80	6.20	0 - 45.8	0.327
IX	2	1	50.00	9.16	21.00	0 - 100	0.010

Figure 2-figure supplement 1B. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate:Cracidae, Odontophoridae and Phasianidae.



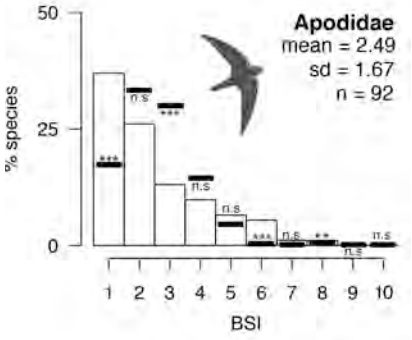
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	31.90	20.00	3.40	8.1 - 31	<0.001
2	33.00	33.00	4.80	16 - 51	0.898
3	13.20	29.00	4.60	13 - 45	<0.001
4	16.50	14.00	3.20	3.4 - 28	0.215
5	2.20	3.70	1.90	0 - 12	0.151
6	0.00	0.60	0.81	0 - 5.8	0.584
7	2.20	0.06	0.26	0 - 2.4	0.002
8	0.00	0.00	0.06	0 - 1.2	0.998
9	1.10	0.00	0.02	0 - 1.1	<0.001
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Caprimulgidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	46	10	21.74	8.61	3.80	0 - 26.1	<0.001
II	56	11	19.64	11.1	3.80	0 - 26.8	0.008
II/III	34	4	11.76	6.83	4.20	0 - 29.4	0.079
III	9	0	0.00	4.83	7.00	0 - 55.6	0.573
IV	11	1	9.09	4.87	6.40	0 - 36.4	0.104
V	33	1	3.03	6.73	4.20	0 - 24.2	0.098
VI	8	1	12.50	4.70	7.40	0 - 50	0.052
VII	9	1	11.11	4.74	7.00	0 - 55.6	0.068
VIII	12	0	0.00	4.93	6.20	0 - 41.7	0.848
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	41.70	29.00	8.70	0 - 50	0.020
2	50.00	49.00	14.00	8.3 - 92	0.712
3	0.00	18.00	9.20	0 - 45	0.057
4	0.00	3.20	4.60	0 - 18	0.652
5	0.00	0.31	1.60	0 - 9.1	0.964
6	8.33	0.01	0.32	0 - 9.1	<0.001
7	0.00	0.00	0.09	0 - 9.1	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

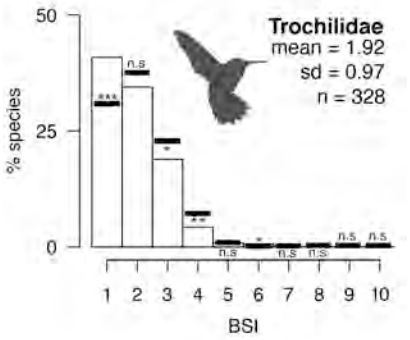
Biome	Podargidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	11	5	45.45	27.00	8.50	0 - 45.5	<0.001
II	7	0	0.00	5.40	6.90	0 - 14.3	0.608
II/III	1	0	0.00	2.50	16.00	0 - 100	0.026
III	1	0	0.00	2.77	16.00	0 - 100	0.029
IV	1	0	0.00	2.42	15.00	0 - 100	0.025
V	1	0	0.00	2.25	15.00	0 - 100	0.023
VI	1	0	0.00	2.40	15.00	0 - 100	0.025
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	37.00	18.00	3.20	5.9 - 30	<0.001
2	26.10	33.00	4.70	17 - 52	0.078
3	13.00	30.00	4.80	13 - 48	<0.001
4	9.78	15.00	3.30	2.2 - 28	0.058
5	6.52	4.20	1.90	0 - 14	0.163
6	5.43	0.75	0.89	0 - 5.7	<0.001
7	1.09	0.08	0.29	0 - 2.3	0.071
8	1.09	0.01	0.08	0 - 1.2	0.005
9	0.00	0.00	0.01	0 - 1.1	1.000
10	0.00	0.00	0.00	0 - 0	1.000

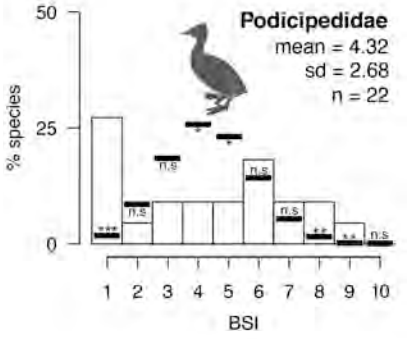
Biome	Apodidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	60	19	31.67	9.72	3.40	0 - 23.3	<0.001
II	55	6	10.91	8.41	3.40	0 - 25.5	0.187
II/III	16	1	6.25	4.00	4.80	0 - 31.2	0.144
III	6	2	33.33	3.72	7.70	0 - 50	0.001
IV	11	0	0.00	3.83	5.80	0 - 36.4	0.535
V	39	5	12.82	5.80	3.60	0 - 25.6	0.019
VI	10	0	0.00	3.77	5.90	0 - 30	0.479
VII	15	1	6.67	3.95	5.00	0 - 33.3	0.129
VIII	13	0	0.00	3.96	5.30	0 - 30.8	0.714
IX	4	0	0.00	3.42	9.10	0 - 75	0.150

Figure 2-figure supplement 1C. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species.
in this plate: Caprimulgidae, Podargidae and Apodidae.



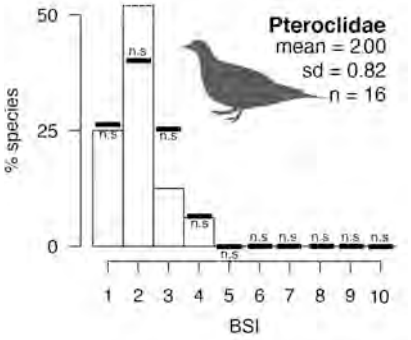
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	40.90	31.00	2.00	24 - 38	<0.001
2	34.50	38.00	2.80	26 - 49	0.150
3	18.90	23.00	2.20	15 - 31	0.036
4	4.27	7.40	1.30	2.7 - 12	0.008
5	0.92	1.30	0.62	0 - 4.8	0.346
6	0.61	0.11	0.19	0 - 1.4	0.045
7	0.00	0.00	0.04	0 - 0.35	0.986
8	0.00	0.00	0.01	0 - 0.34	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Trochilidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	158	41	25.95	17.50	2.70	8.23-27.8	0.001
II	125	21	16.80	14.70	2.90	4 - 25.6	0.237
II/III	34	3	8.82	10.10	5.00	0 - 32.4	0.836
III	11	4	36.36	9.38	8.80	0 - 63.6	0.003
IV	6	0	0.00	9.05	12.00	0 - 66.7	0.778
V	150	33	22.00	16.70	2.70	7.33 - 28	0.022
VI	8	0	0.00	9.40	10.00	0 - 62.5	<0.001
VII	64	26	40.62	11.30	3.80	0 - 28.1	<0.001
VIII	72	6	8.33	11.60	3.60	0 - 26.4	0.159
IX	1	0	0.00	8.78	28.00	0 - 100	0.096



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	27.30	2.20	3.00	0 - 18	<0.001
2	4.55	8.60	5.30	0 - 27	0.117
3	9.09	19.00	7.60	0 - 50	0.052
4	9.09	26.00	9.30	0 - 68	0.013
5	9.09	23.00	8.70	0 - 62	0.020
6	18.20	14.00	6.70	0 - 41	0.225
7	9.09	5.70	4.50	0 - 27	0.139
8	9.09	1.40	2.40	0 - 19	0.004
9	4.55	0.20	0.95	0 - 9.1	0.004
10	0.00	0.01	0.23	0 - 4.5	0.997

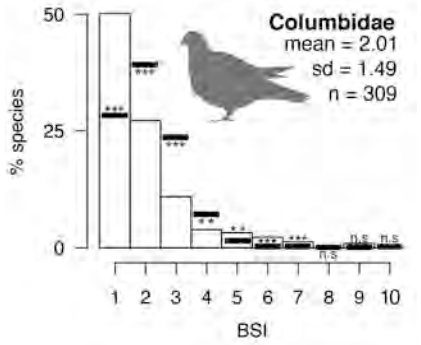
Biome	Podicipedidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	5	0	0.00	0.33	2.60	0 - 40	0.017
II	10	1	10.00	0.45	2.10	0 - 20	<0.001
II/III	10	0	0.00	0.46	2.10	0 - 20	0.047
III	7	0	0.00	0.36	2.30	0 - 28.6	0.025
IV	11	0	0.00	0.53	2.20	0 - 18.2	0.061
V	10	1	10.00	0.45	2.10	0 - 20	0.001
VI	14	0	0.00	0.71	2.20	0 - 14.3	0.108
VII	14	3	21.43	0.68	2.20	0 - 14.3	<0.001
VIII	10	1	10.00	0.45	2.10	0 - 20	0.001
IX	4	0	0.00	0.29	2.70	0 - 50	0.012



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	25.00	27.00	8.90	0 - 56	0.498
2	56.20	40.00	13.00	0 - 93	0.107
3	12.50	25.00	10.00	0 - 62	0.055
4	6.25	6.90	5.80	0 - 31	0.403
5	0.00	0.67	2.10	0 - 15	0.904
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

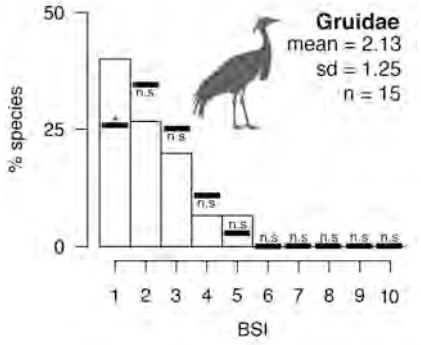
Biome	Pteroclidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	9	0	0.00	14.40	10.00	0 - 55.6	<0.001
II/III	10	0	0.00	16.70	10.00	0 - 60	<0.001
III	6	2	33.33	9.99	11.00	0 - 66.7	0.007
IV	3	0	0.00	7.59	15.00	0 - 100	0.275
V	0	0	0.00	0.00	0.00	0 - 0	1.000
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	4	2	50.00	8.27	13.00	0 - 75	0.001
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 1D. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Trochilidae, Podicipedidae and Pteroclidae.



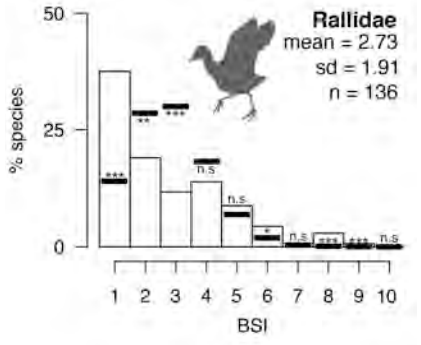
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	50.20	28.00	2.00	20 - 35	<0.001
2	27.20	39.00	2.80	29 - 50	<0.001
3	11.00	24.00	2.20	15 - 34	<0.001
4	3.88	7.30	1.30	2.7 - 12	0.004
5	3.24	1.30	0.62	0 - 3.8	0.002
6	2.27	0.13	0.21	0 - 1.4	<0.001
7	1.29	0.01	0.05	0 - 0.36	<0.001
8	0.00	0.00	0.01	0 - 0.35	1.000
9	0.97	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Columbidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	211	103	48.82	20.00	2.20	11.8 - 28.4	<0.001
II	158	35	22.15	13.00	2.30	5.06 - 24.1	<0.001
II/III	49	2	4.08	7.56	3.70	0 - 26.5	0.109
III	25	2	8.00	6.91	5.00	0 - 32	0.323
IV	22	0	0.00	6.81	5.40	0 - 36.4	<0.001
V	90	8	8.89	8.97	2.80	0 - 23.3	0.710
VI	19	0	0.00	6.67	5.70	0 - 36.8	<0.001
VII	25	5	20.00	6.86	5.00	0 - 28	0.004
VIII	18	0	0.00	6.65	5.90	0 - 38.9	<0.001
IX	3	0	0.00	6.36	14.00	0 - 100	0.217



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	40.00	26.00	9.40	0 - 57	0.047
2	26.70	34.00	13.00	0 - 93	0.327
3	20.00	25.00	11.00	0 - 75	0.356
4	6.67	11.00	7.50	0 - 45	0.194
5	6.67	2.90	4.40	0 - 27	0.410
6	0.00	0.47	1.80	0 - 15	0.937
7	0.00	0.04	0.54	0 - 9.1	0.995
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

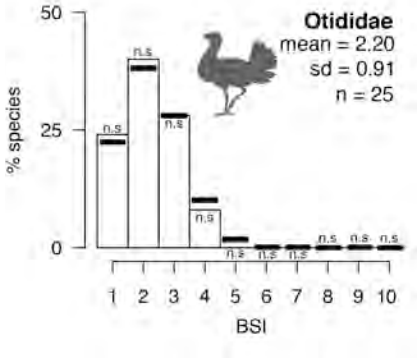
Biome	Gruidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	6	0	0.00	12.80	13.00	0 - 66.7	<0.001
II/III	4	0	0.00	10.70	15.00	0 - 75	0.593
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	2	0	0.00	8.79	20.00	0 - 100	0.205
V	3	0	0.00	9.77	17.00	0 - 100	0.371
VI	5	1	20.00	11.70	14.00	0 - 80	0.107
VII	6	3	50.00	12.70	13.00	0 - 66.7	0.001
VIII	4	1	25.00	10.70	15.00	0 - 100	0.055
IX	2	1	50.00	9.23	20.00	0 - 100	0.006



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	37.50	14.00	2.50	5.2 - 24	<0.001
2	19.10	29.00	3.60	14 - 43	0.004
3	11.80	30.00	4.00	16 - 44	<0.001
4	14.00	18.00	3.00	7.5 - 31	0.074
5	8.82	6.80	2.00	0.75 - 17	0.199
6	4.41	1.60	1.00	0 - 6.9	0.014
7	0.74	0.22	0.40	0 - 2.3	0.329
8	2.94	0.02	0.11	0 - 1.6	<0.001
9	0.74	0.00	0.02	0 - 0.77	0.001
10	0.00	0.00	0.00	0 - 0	1.000

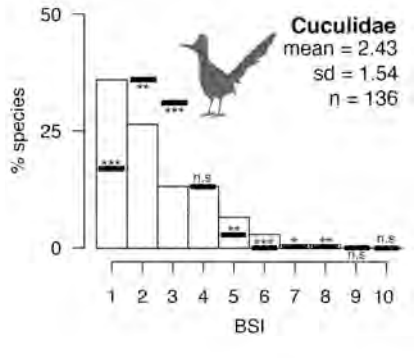
Biome	Rallidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	82	24	29.27	6.97	2.60	0 - 17.1	<0.001
II	79	12	15.19	6.59	2.60	0 - 19	0.001
II/III	38	0	0.00	3.84	3.00	0 - 18.4	<0.001
III	10	0	0.00	3.05	5.40	0 - 30	0.367
IV	29	0	0.00	3.50	3.40	0 - 20.7	<0.001
V	54	6	11.11	4.63	2.70	0 - 16.7	0.008
VI	31	3	9.68	3.57	3.30	0 - 22.6	0.022
VII	27	4	14.81	3.44	3.40	0 - 25.9	0.001
VIII	19	1	5.26	3.18	4.00	0 - 26.3	0.137
IX	2	1	50.00	2.92	12.00	0 - 100	0.001

Figure 2-figure supplement 1E. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Columbidae, Gruidae and Rallidae.



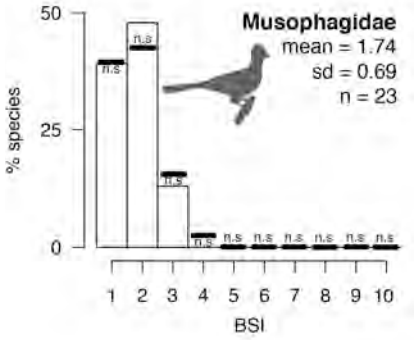
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	24.00	22.00	6.60	0 - 48	0.624
2	40.00	38.00	9.80	4.2 - 80	0.658
3	28.00	28.00	8.50	4 - 64	0.965
4	8.00	9.60	5.20	0 - 33	0.368
5	0.00	1.50	2.30	0 - 17	0.692
6	0.00	0.10	0.64	0 - 9.1	0.977
7	0.00	0.00	0.10	0 - 4.8	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Otididae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	12	1	8.333	8.16	7.20	0 - 41.7	0.332
II/III	18	3	16.67	15.30	7.00	0 - 50	0.376
III	12	1	8.333	8.04	7.20	0 - 41.7	0.324
IV	7	1	14.29	5.82	8.60	0 - 57.1	0.055
V	2	0	0.00	4.63	15.00	0 - 100	0.099
VI	1	0	0.00	4.34	20.00	0 - 100	0.045
VII	3	0	0.00	4.79	12.00	0 - 66.7	0.159
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	36.00	17.00	2.50	8.5 - 26	<0.001
2	26.50	36.00	3.90	22 - 52	0.008
3	13.20	31.00	3.80	17 - 48	<0.001
4	13.20	13.00	2.40	3 - 22	0.805
5	6.62	2.80	1.30	0 - 9.3	0.007
6	2.94	0.33	0.49	0 - 3.1	<0.001
7	0.74	0.03	0.14	0 - 1.5	0.036
8	0.74	0.00	0.02	0 - 0.77	0.001
9	0.00	0.00	0.01	0 - 0.75	1.000
10	0.00	0.00	0.00	0 - 0	1.000

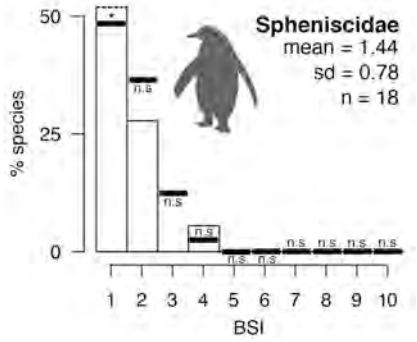
Biome	Cuculidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	103	37	35.92	10.60	2.60	0.97-22.3	<0.001
II	90	9	10.00	7.57	2.40	0 - 17.8	0.126
II/III	40	2	5.00	3.68	2.90	0 - 17.5	0.214
III	5	0	0.00	2.68	7.20	0 - 40	0.147
IV	11	0	0.00	2.76	5.00	0 - 36.4	0.356
V	45	1	2.22	3.86	2.80	0 - 15.6	0.188
VI	18	0	0.00	2.93	3.90	0 - 22.2	0.728
VII	9	0	0.00	2.71	5.40	0 - 33.3	0.282
VIII	8	0	0.00	2.74	5.70	0 - 37.5	0.250
IX	2	0	0.00	2.42	11.00	0 - 100	0.050



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	39.10	40.00	6.40	18 - 61	0.990
2	47.80	43.00	10.00	8.7 - 82	0.323
3	13.00	16.00	5.90	0 - 38	0.270
4	0.00	2.00	2.70	0 - 18	0.622
5	0.00	0.00	0.00	0 - 0	1.000
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

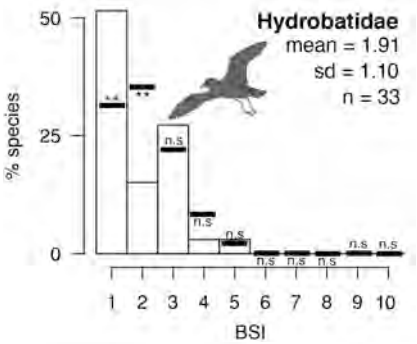
Biome	Musophagidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	6	1	16.67	4.59	8.10	0 - 33.3	0.018
II	21	7	33.33	38.00	6.50	14.3 - 61.9	0.150
II/III	6	1	16.67	4.56	8.00	0 - 33.3	0.017
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	7	0	0.00	4.72	7.40	0 - 28.6	0.442
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 1F. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Otididae, Cuculidae and Musophagidae.



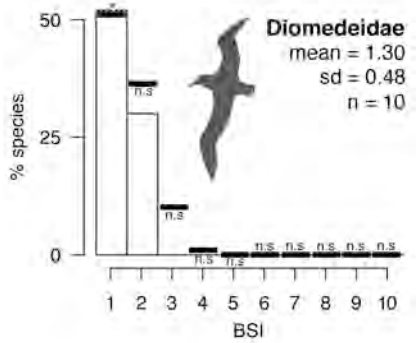
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	66.70	48.00	9.40	8.3 - 76	0.012
2	27.80	36.00	12.00	0 - 86	0.328
3	0.00	13.00	7.30	0 - 46	0.083
4	5.56	2.30	3.60	0 - 23	0.455
5	0.00	0.24	1.30	0 - 15	0.965
6	0.00	0.01	0.27	0 - 7.7	0.998
7	0.00	0.00	0.07	0 - 6.7	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Spheniscidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	1	1	100.00	14.90	36.00	0 - 100	<0.001
II/III	0	0	0.00	0.00	0.00	0 - 0	1.000
III	2	0	0.00	16.10	26.00	0 - 100	0.427
IV	2	0	0.00	16.20	26.00	0 - 100	0.433
V	3	1	33.33	17.30	21.00	0 - 100	0.075
VI	3	0	0.00	17.10	21.00	0 - 100	0.796
VII	3	1	33.33	17.30	21.00	0 - 100	0.075
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	12	9	75.00	43.20	11.00	8.33 - 83.3	<0.001



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	51.50	32.00	6.80	4 - 56	0.002
2	15.20	35.00	8.70	6.5 - 67	0.009
3	27.30	22.00	7.00	0 - 56	0.303
4	3.03	8.40	4.60	0 - 27	0.057
5	3.03	2.10	2.50	0 - 17	0.902
6	0.00	0.34	1.10	0 - 8	0.904
7	0.00	0.04	0.35	0 - 4.2	0.990
8	0.00	0.00	0.07	0 - 3.6	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

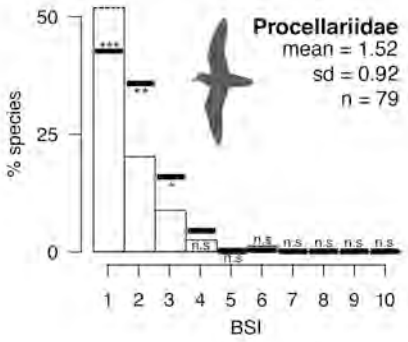
Biome	Hydrobatidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	4	1	25.00	12.40	16.00	0 - 100	0.084
II	4	0	0.00	12.40	16.00	0 - 100	0.709
II/III	2	0	0.00	11.60	22.00	0 - 100	0.283
III	7	3	42.86	14.10	13.00	0 - 71.4	0.006
IV	7	0	0.00	13.90	13.00	0 - 71.4	<0.001
V	9	2	22.22	15.00	11.00	0 - 66.7	0.147
VI	11	2	18.18	16.30	11.00	0 - 63.6	0.346
VII	3	1	33.33	12.00	19.00	0 - 100	0.038
VIII	3	0	0.00	12.00	19.00	0 - 100	0.471
IX	13	8	61.54	18.00	9.70	0 - 61.5	<0.001



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	70.00	52.00	14.00	0 - 90	0.039
2	30.00	36.00	16.00	0 - 86	0.583
3	0.00	10.00	9.60	0 - 50	0.361
4	0.00	1.10	3.80	0 - 33	0.915
5	0.00	0.04	0.73	0 - 17	0.997
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

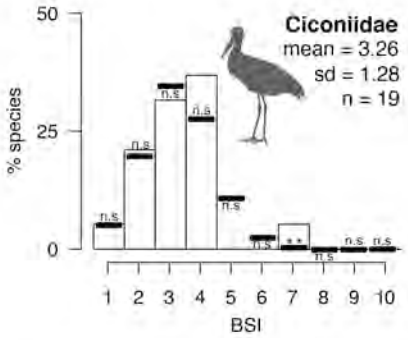
Biome	Diomedeidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	1	0	0.00	19.90	40.00	0 - 100	0.249
II/III	0	0	0.00	0.00	0.00	0 - 0	1.000
III	1	0	0.00	19.80	40.00	0 - 100	0.247
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	3	3	100.00	25.90	23.00	0 - 100	<0.001
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	2	0	0.00	22.90	29.00	0 - 100	0.722
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	6	4	66.67	45.30	16.00	0 - 100	0.024

Figure 2-figure supplement 1G. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Spheniscidae, Hydrobatidae and Diomedeidae.



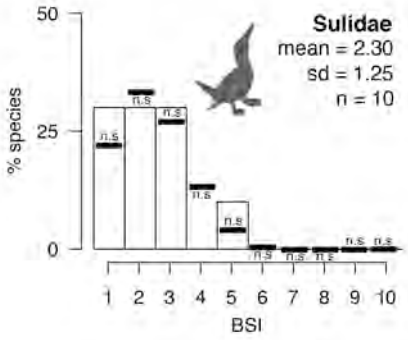
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	67.10	43.00	4.80	22 - 60	<0.001
2	20.30	36.00	5.90	14 - 58	0.004
3	8.86	16.00	4.10	3.2 - 34	0.034
4	2.53	4.30	2.30	0 - 15	0.239
5	0.00	0.72	1.00	0 - 7.8	0.618
6	1.27	0.07	0.34	0 - 3.5	0.048
7	0.00	0.01	0.09	0 - 1.7	0.996
8	0.00	0.00	0.02	0 - 1.6	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Procellariidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	17	12	70.59	22.10	9.50	0 - 58.8	<0.001
II	5	3	60.00	18.70	17.00	0 - 100	0.004
II/III	3	2	66.67	18.20	22.00	0 - 100	0.006
III	3	2	66.67	18.40	22.00	0 - 100	0.007
IV	10	3	30.00	20.00	12.00	0 - 80	0.138
V	30	13	43.33	28.10	7.30	3.33 - 56.7	0.013
VI	16	2	12.50	21.90	9.80	0 - 62.5	0.101
VII	10	3	30.00	20.10	12.00	0 - 70	0.134
VIII	3	0	0.00	18.40	22.00	0 - 100	0.843
IX	23	13	56.52	24.70	8.20	0 - 65.2	<0.001



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	5.26	4.80	4.40	0 - 26	0.336
2	21.10	20.00	7.70	0 - 47	0.466
3	31.60	34.00	11.00	0 - 79	0.465
4	36.80	27.00	9.50	0 - 63	0.123
5	0.00	11.00	6.10	0 - 37	0.077
6	0.00	2.40	3.20	0 - 21	0.610
7	5.26	0.24	1.10	0 - 11	0.005
8	0.00	0.01	0.27	0 - 5.6	0.997
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

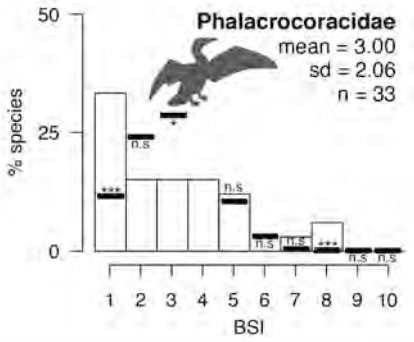
Biome	Ciconiidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	13	1	7.69	1.35	3.10	0 - 15.4	0.007
II	16	0	0.00	2.64	3.80	0 - 25	0.579
II/III	14	0	0.00	1.57	3.20	0 - 21.4	0.263
III	3	0	0.00	0.51	4.10	0 - 33.3	0.016
IV	2	0	0.00	0.37	4.30	0 - 50	0.007
V	7	0	0.00	0.64	3.00	0 - 28.6	0.046
VI	3	0	0.00	0.55	4.20	0 - 33.3	0.017
VII	3	0	0.00	0.39	3.60	0 - 33.3	0.012
VIII	1	0	0.00	0.44	6.60	0 - 100	0.004
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	30.00	22.00	11.00	0 - 60	0.208
2	30.00	33.00	15.00	0 - 80	0.533
3	30.00	27.00	14.00	0 - 88	0.558
4	0.00	13.00	10.00	0 - 57	0.227
5	10.00	3.90	6.00	0 - 43	0.273
6	0.00	0.69	2.70	0 - 25	0.938
7	0.00	0.07	0.86	0 - 14	0.994
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

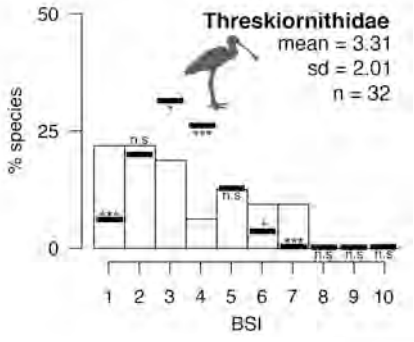
Biome	Sulidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	4	1	25.00	9.86	14.00	0 - 75	0.041
II	5	1	20.00	11.90	13.00	0 - 80	0.103
II/III	3	0	0.00	8.51	16.00	0 - 66.7	0.319
III	3	1	33.33	8.30	15.00	0 - 100	0.013
IV	2	0	0.00	7.20	18.00	0 - 100	0.163
V	3	0	0.00	8.49	16.00	0 - 100	0.317
VI	2	0	0.00	7.32	18.00	0 - 100	0.165
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	1	0	0.00	6.55	25.00	0 - 100	0.070
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 1H. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Procellariidae, Ciconiidae and Sulidae.



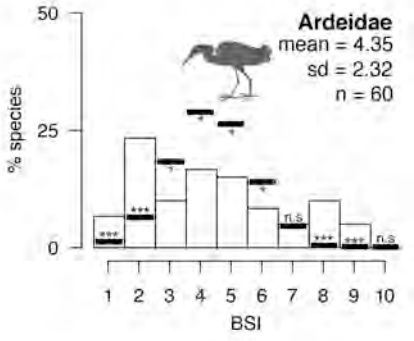
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	33.30	12.00	4.80	0 - 33	<0.001
2	15.20	24.00	6.70	3.1 - 52	0.071
3	15.20	28.00	7.90	0 - 61	0.031
4	15.20	21.00	6.80	0 - 52	0.168
5	12.10	10.00	4.80	0 - 30	0.576
6	0.00	3.40	3.00	0 - 19	0.302
7	3.03	0.77	1.50	0 - 9.7	0.184
8	6.06	0.11	0.58	0 - 6.7	<0.001
9	0.00	0.01	0.16	0 - 3.3	0.997
10	0.00	0.00	0.03	0 - 3	1.000

Biome	Phalacrocoracidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	5	0	0.00	2.93	7.40	0 - 60	0.163
II	11	1	9.09	3.71	5.60	0 - 36.4	0.058
II/III	7	0	0.00	3.15	6.50	0 - 42.9	0.254
III	11	1	9.09	3.81	5.60	0 - 36.4	0.061
IV	13	0	0.00	4.10	5.40	0 - 38.5	0.743
V	12	0	0.00	3.93	5.40	0 - 41.7	0.649
VI	16	3	18.75	4.87	5.20	0 - 31.2	0.003
VII	11	3	27.27	3.80	5.70	0 - 36.4	0.001
VIII	4	0	0.00	2.83	8.20	0 - 75	0.123
IX	9	3	33.33	3.39	5.90	0 - 44.4	<0.001



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	21.90	6.30	3.80	0 - 22	<0.001
2	21.90	20.00	6.00	0 - 41	0.414
3	18.80	31.00	8.10	3.1 - 65	0.044
4	6.25	26.00	7.30	0 - 53	<0.001
5	12.50	13.00	5.20	0 - 33	0.779
6	9.38	3.80	3.10	0 - 19	0.039
7	9.38	0.61	1.30	0 - 9.7	<0.001
8	0.00	0.04	0.36	0 - 3.3	0.987
9	0.00	0.00	0.06	0 - 3.2	1.000
10	0.00	0.00	0.00	0 - 0	1.000

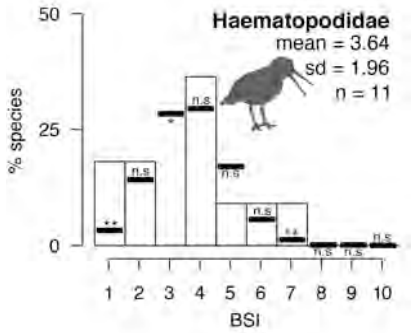
Biome	Threskiornithidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	13	1	7.69	1.06	2.80	0 - 23.1	0.007
II	27	2	7.41	4.21	3.50	0 - 18.5	0.094
II/III	18	0	0.00	1.50	2.80	0 - 16.7	0.322
III	8	0	0.00	0.85	3.20	0 - 25	0.071
IV	10	1	10.00	0.91	3.00	0 - 30	0.002
V	15	0	0.00	1.22	2.80	0 - 20	0.207
VI	9	2	22.22	0.89	3.10	0 - 22.2	<0.001
VII	5	1	20.00	0.81	4.00	0 - 40	<0.001
VIII	1	0	0.00	0.58	7.60	0 - 100	0.006
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	6.67	1.10	1.30	0 - 8.3	<0.001
2	23.30	6.50	2.80	0 - 20	<0.001
3	10.00	18.00	4.40	3.3 - 35	0.013
4	16.70	29.00	5.70	10 - 52	0.009
5	15.00	26.00	5.40	6.7 - 50	0.011
6	8.33	14.00	3.80	1.7 - 28	0.041
7	5.00	4.20	2.30	0 - 15	0.318
8	10.00	0.65	0.99	0 - 6.7	<0.001
9	5.00	0.04	0.24	0 - 3.4	<0.001
10	0.00	0.00	0.00	0 - 0	1.000

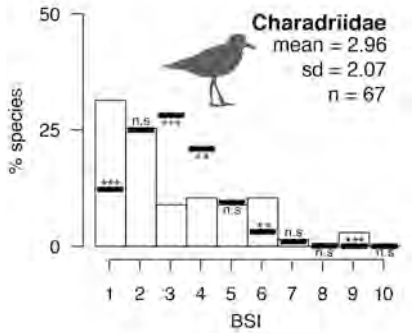
Biome	Ardeidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	42	0	0.00	0.19	0.66	0 - 7.14	0.082
II	55	2	3.64	0.69	1.10	0 - 7.27	0.005
II/III	34	0	0.00	0.14	0.63	0 - 5.88	0.047
III	20	0	0.00	0.09	0.68	0 - 10	0.019
IV	21	0	0.00	0.08	0.63	0 - 4.76	0.018
V	38	0	0.00	0.15	0.62	0 - 5.26	0.059
VI	30	2	6.67	0.12	0.62	0 - 6.67	<0.001
VII	14	0	0.00	0.07	0.72	0 - 7.14	0.010
VIII	7	0	0.00	0.09	1.10	0 - 14.3	0.006
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 1l. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Phalacrocoracidae, Threskiornithidae and Ardeidae.



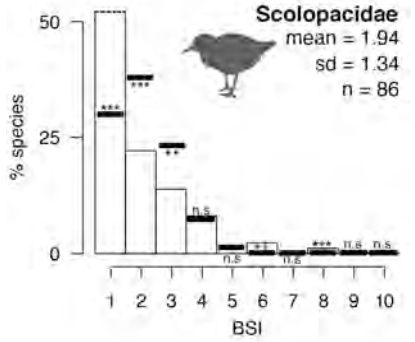
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	18.20	3.50	5.10	0 - 27	0.002
2	18.20	15.00	9.10	0 - 45	0.226
3	0.00	28.00	13.00	0 - 73	0.022
4	36.40	29.00	14.00	0 - 82	0.243
5	9.09	17.00	10.00	0 - 55	0.107
6	9.09	5.80	6.30	0 - 30	0.145
7	9.09	1.20	3.20	0 - 27	0.011
8	0.00	0.11	1.00	0 - 10	0.988
9	0.00	0.01	0.26	0 - 10	0.999
10	0.00	0.00	0.09	0 - 9.1	1.000

Biome	Haematopodidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	1	0	0.00	0.23	4.80	0 - 100	0.002
II	3	0	0.00	0.43	3.80	0 - 33.3	0.013
II/III	1	0	0.00	0.43	6.50	0 - 100	0.004
III	4	0	0.00	0.53	3.60	0 - 50	0.022
IV	8	1	12.50	1.20	3.70	0 - 25	0.002
V	9	1	11.11	1.68	4.20	0 - 33.3	0.006
VI	7	0	0.00	0.89	3.50	0 - 28.6	0.066
VII	4	0	0.00	0.50	3.50	0 - 25	0.021
VIII	1	0	0.00	0.33	5.70	0 - 100	0.003
IX	2	0	0.00	0.37	4.30	0 - 50	0.007



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	31.30	12.00	3.40	1.5 - 27	<0.001
2	25.40	25.00	4.80	9.1 - 44	0.789
3	8.96	28.00	5.60	9.1 - 49	<0.001
4	10.40	21.00	4.70	4.5 - 39	0.008
5	8.96	10.00	3.30	0 - 22	0.493
6	10.40	3.30	2.00	0 - 12	0.002
7	1.49	0.70	1.00	0 - 6.7	0.508
8	0.00	0.09	0.37	0 - 3.3	0.943
9	2.99	0.01	0.11	0 - 1.6	<0.001
10	0.00	0.00	0.03	0 - 1.6	1.000

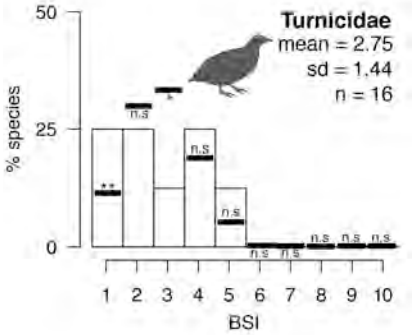
Biome	Charadriidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	16	0	0.00	3.56	4.70	0 - 31.2	0.776
II	34	5	14.71	5.42	3.70	0 - 20.6	0.006
II/III	22	0	0.00	3.97	4.10	0 - 22.7	<0.001
III	17	0	0.00	3.59	4.40	0 - 35.3	0.882
IV	24	0	0.00	4.19	4.00	0 - 25	<0.001
V	21	1	4.76	3.89	4.10	0 - 28.6	0.238
VI	24	3	12.50	4.11	3.90	0 - 25	0.013
VII	22	9	40.91	3.99	4.00	0 - 27.3	<0.001
VIII	8	0	0.00	3.16	6.10	0 - 37.5	0.300
IX	10	3	30.00	3.14	5.50	0 - 40	<0.001



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	52.30	30.00	4.00	15 - 45	<0.001
2	22.10	38.00	5.40	20 - 57	<0.001
3	14.00	23.00	4.30	5.1 - 41	0.016
4	8.14	7.40	2.60	0 - 21	0.542
5	0.00	1.30	1.20	0 - 8.1	0.345
6	2.33	0.12	0.39	0 - 3.8	0.004
7	0.00	0.01	0.08	0 - 1.4	0.996
8	1.16	0.00	0.02	0 – 1.2	<0.001
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

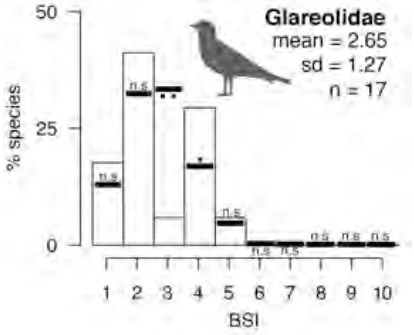
Biome	Scolopacidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	5	1	20.00	8.64	12.00	0 - 80	0.066
II	5	1	20.00	8.77	13.00	0 - 80	0.066
II/III	3	0	0.00	8.38	16.00	0 - 100	0.301
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	4	0	0.00	9.04	14.00	0 - 75	0.458
V	12	3	25.00	9.59	8.30	0 - 50	0.020
VI	27	1	3.70	12.10	5.90	0 - 37	0.022
VII	22	1	4.55	11.20	6.40	0 - 45.5	0.071
VIII	46	12	26.09	17.90	4.80	2.17-39.1	0.032
IX	43	26	60.47	16.70	5.00	2.33-37.2	<0.001

Figure 2-figure supplement 1J. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Haematopodidae, Charadriidae and Scolopacidae.



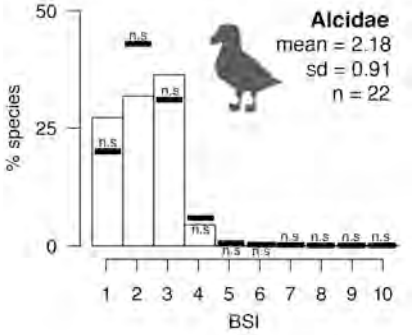
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	25.00	12.00	6.60	0 - 38	0.010
2	25.00	30.00	10.00	0 - 69	0.283
3	12.50	33.00	12.00	0 - 80	0.014
4	25.00	19.00	8.40	0 - 50	0.199
5	12.50	5.30	5.00	0 - 29	0.066
6	0.00	0.70	2.10	0 - 13	0.893
7	0.00	0.03	0.44	0 - 6.7	0.995
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Turnicidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	6	0	0.00	1.82	5.30	0 - 33.3	0.120
II	14	2	14.29	8.94	6.60	0 - 35.7	0.101
II/III	9	1	11.11	2.52	4.90	0 - 22.2	0.011
III	1	0	0.00	1.23	11.00	0 - 100	0.013
IV	5	0	0.00	1.73	5.70	0 - 40	0.092
V	6	1	16.67	1.80	5.30	0 - 33.3	0.002
VI	3	0	0.00	1.34	6.60	0 - 66.7	0.042
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	17.60	13.00	6.50	0 - 35	0.174
2	41.20	32.00	10.00	0 - 65	0.153
3	5.88	33.00	11.00	0 - 81	0.001
4	29.40	17.00	7.70	0 - 47	0.049
5	5.88	4.30	4.40	0 - 25	0.330
6	0.00	0.51	1.70	0 - 13	0.917
7	0.00	0.01	0.29	0 - 7.1	0.998
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

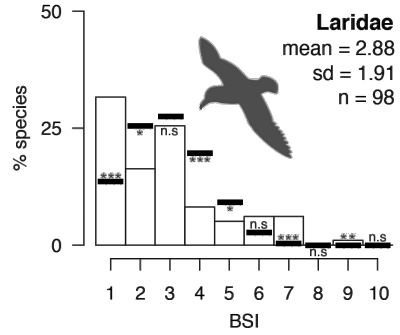
Biome	Glareolidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	4	0	0.00	2.00	7.00	0 - 75	0.085
II	14	2	14.29	8.88	6.60	0 - 42.9	0.100
II/III	11	0	0.00	4.41	5.60	0 - 27.3	0.728
III	6	0	0.00	2.42	6.10	0 - 33.3	0.163
IV	5	0	0.00	2.30	6.60	0 - 60	0.126
V	0	0	0.00	0.00	0.00	0 - 0	1.000
VI	1	0	0.00	1.70	13.00	0 - 100	0.017
VII	4	1	25.00	1.95	6.80	0 - 50	0.001
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	27.30	20.00	6.30	0 - 41	0.093
2	31.80	43.00	10.00	9.1 - 82	0.133
3	36.40	31.00	8.30	0 - 68	0.283
4	4.55	6.10	4.30	0 - 25	0.240
5	0.00	0.44	1.40	0 - 10	0.908
6	0.00	0.01	0.22	0 - 5	0.998
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

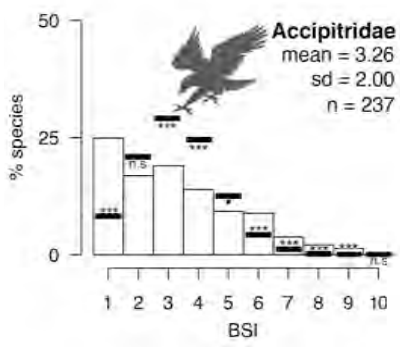
Biome	Alcidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	0	0	0.00	0.00	0.00	0 - 0	1.000
II/III	0	0	0.00	0.00	0.00	0 - 0	1.000
III	2	1	50.00	3.04	12.00	0 - 100	0.001
IV	2	0	0.00	3.00	12.00	0 - 100	0.063
V	1	0	0.00	2.78	16.00	0 - 100	0.029
VI	11	0	0.00	5.19	6.10	0 - 27.3	0.891
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	14	0	0.00	7.16	5.90	0 - 28.6	<0.001
IX	18	5	27.78	14.40	6.50	0 - 38.9	0.006

Figure 2-figure supplement 1K. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Turnicidae, Glareolidae and Alcidae.



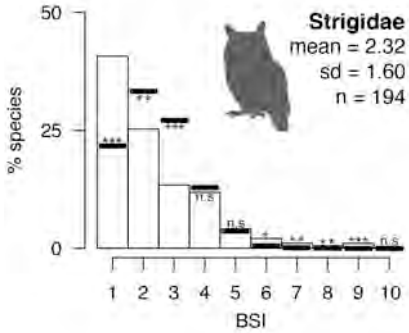
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	31.60	14.00	3.00	4.3 - 24	<0.001
2	16.30	26.00	4.10	10 - 41	0.013
3	25.50	28.00	4.60	12 - 44	0.464
4	8.16	20.00	3.80	6.3 - 34	<0.001
5	5.10	9.30	2.70	1.1 - 21	0.035
6	6.12	3.10	1.70	0 - 11	0.057
7	6.12	0.68	0.82	0 - 5.3	<0.001
8	0.00	0.11	0.33	0 - 3.2	0.904
9	1.02	0.01	0.09	0 - 1.1	0.007
10	0.00	0.00	0.02	0 - 1.1	1.000

Biome	Laridae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	29	1	3.45	4.59	3.80	0 - 20.7	0.655
II	34	2	5.88	5.03	3.70	0 - 23.5	0.320
II/III	22	0	0.00	4.2	4.10	0 - 22.7	<0.001
III	26	8	30.77	4.47	4.00	0 - 19.2	<0.001
IV	27	1	3.70	4.36	3.90	0 - 22.2	0.495
V	31	1	3.23	4.74	3.60	0 - 22.6	0.789
VI	40	1	2.50	5.42	3.50	0 - 20	0.114
VII	31	6	19.35	4.79	3.70	0 - 22.6	<0.001
VIII	20	1	5.00	4.01	4.30	0 - 25	0.235
IX	22	10	45.45	4.19	4.20	0 - 22.7	<0.001



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	24.90	8.10	1.60	3 - 14	<0.001
2	16.90	21.00	2.30	12 - 30	0.053
3	19.00	29.00	2.90	18 - 41	<0.001
4	13.90	24.00	2.70	15 - 35	<0.001
5	9.28	13.00	1.90	5.6 - 21	0.028
6	8.86	4.30	1.20	0.85 - 9.9	<0.001
7	3.80	0.91	0.60	0 - 3.8	<0.001
8	2.11	0.11	0.21	0 - 1.3	<0.001
9	1.27	0.01	0.06	0 - 0.86	<0.001
10	0.00	0.00	0.01	0 - 0.43	0.999

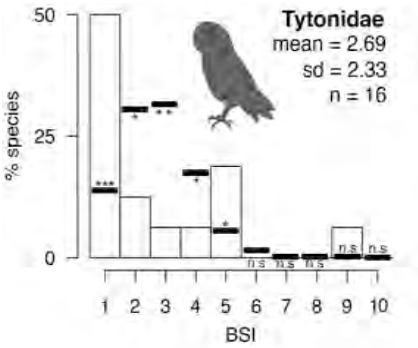
Biome	Accipitridae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	144	39	27.08	3.34	1.40	0 - 9.72	<0.001
II	137	4	2.92	3.11	1.40	0 - 9.49	0.739
II/III	112	3	2.68	2.46	1.40	0 - 8.93	0.416
III	47	0	0.00	1.64	1.80	0 - 10.6	<0.001
IV	57	1	1.75	1.76	1.70	0 - 10.5	0.361
V	108	3	2.78	2.40	1.40	0 - 9.26	0.348
VI	51	0	0.00	1.70	1.80	0 - 13.7	<0.001
VII	61	7	11.48	1.78	1.70	0 - 11.5	<0.001
VIII	43	1	2.33	1.60	1.90	0 - 11.6	0.178
IX	12	1	8.33	1.33	3.30	0 - 25	0.010



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	40.70	22.00	2.40	13 - 30	<0.001
2	25.30	33.00	3.40	21 - 45	0.007
3	13.40	27.00	3.20	15 - 39	<0.001
4	11.90	13.00	2.20	5.4 - 22	0.439
5	4.12	3.80	1.30	0 - 10	0.632
6	2.06	0.69	0.60	0 - 3.9	0.036
7	1.03	0.07	0.20	0 - 1.7	0.008
8	0.52	0.01	0.05	0 - 0.56	0.009
9	1.03	0.00	0.01	0 - 0.57	<0.001
10	0.00	0.00	0.00	0 - 0	1.000

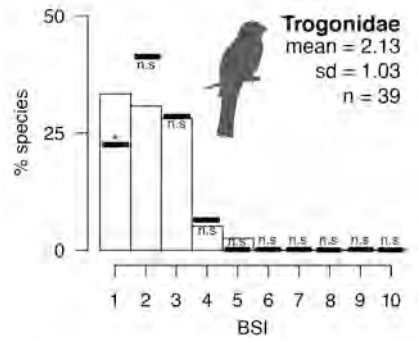
Biome	Strigidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	98	41	41.84	11.00	2.90	2.04 - 22.4	<0.001
II	98	18	18.37	11.00	2.90	2.04 - 23.5	0.006
II/III	41	2	4.88	6.91	3.80	0 - 24.4	0.258
III	21	1	4.76	6.20	5.20	0 - 28.6	0.605
IV	21	0	0.00	6.08	5.10	0 - 28.6	<0.001
V	76	14	18.42	8.96	3.10	0 - 22.4	0.001
VI	38	0	0.00	6.66	4.00	0 - 23.7	<0.001
VII	19	0	0.00	5.92	5.30	0 - 31.6	<0.001
VIII	36	2	5.56	6.70	4.10	0 - 25	0.782
IX	3	1	33.33	5.62	13.00	0 - 66.7	0.009

Figure 2-figure supplement 1L. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Laridae, Accipitridae and Strigidae.



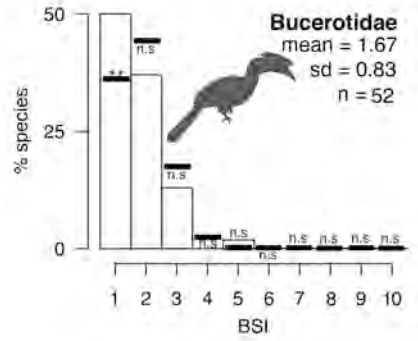
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	50.00	14.00	7.20	0 - 44	<0.001
2	12.50	30.00	11.00	0 - 69	0.024
3	6.25	31.00	12.00	0 - 80	0.003
4	6.25	18.00	8.50	0 - 50	0.030
5	18.80	5.70	5.30	0 - 29	0.016
6	0.00	1.10	2.60	0 - 14	0.837
7	0.00	0.12	0.89	0 - 13	0.981
8	0.00	0.01	0.20	0 - 6.7	0.999
9	6.25	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Tytonidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	12	6	50.00	8.92	7.30	0 - 41.7	<0.001
II	9	1	11.11	4.93	6.70	0 - 33.3	0.056
II/III	3	0	0.00	2.74	9.40	0 - 66.7	0.088
III	1	0	0.00	2.15	15.00	0 - 100	0.022
IV	2	0	0.00	2.46	11.00	0 - 100	0.051
V	7	1	14.29	3.89	7.00	0 - 57.1	0.020
VI	3	0	0.00	2.58	9.00	0 - 66.7	0.083
VII	3	0	0.00	2.66	9.20	0 - 66.7	0.085
VIII	3	0	0.00	2.79	9.50	0 - 66.7	0.089
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	33.30	23.00	5.00	5.4 - 44	0.010
2	30.80	41.00	7.80	11 - 68	0.086
3	28.20	29.00	6.20	7.7 - 53	0.729
4	5.13	6.6	3.40	0 - 26	0.291
5	2.56	0.36	0.95	0 - 5.7	0.124
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

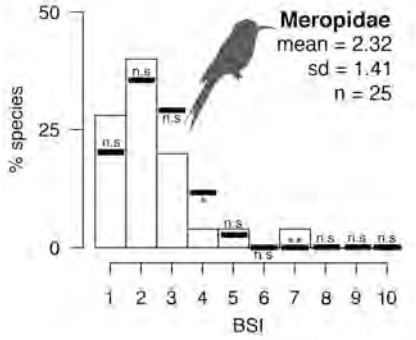
Biome	Trogonidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	30	10	33.33	15.70	5.10	0 - 36.7	<0.001
II	20	2	10.00	7.48	5.00	0 - 30	0.195
II/III	3	0	0.00	3.89	8.90	0 - 100	0.126
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	22	1	4.55	8.22	4.80	0 – 31.8	0.128
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	8	0	0.00	4.60	7.20	0 - 50	0.470
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	50.00	37.00	5.20	19 - 54	0.004
2	36.50	44.00	7.00	13 - 67	0.162
3	11.50	16.00	4.50	2 - 32	0.169
4	0.00	2.20	2.00	0 - 11	0.319
5	1.92	0.12	0.50	0 - 4.5	0.060
6	0.00	0.00	0.078	0 - 2.2	0.999
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

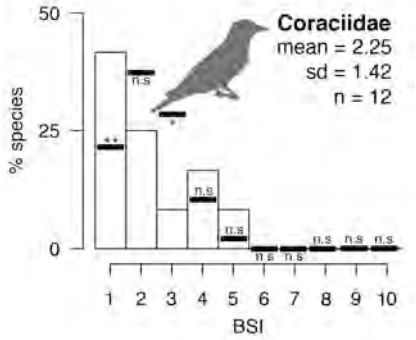
Biome	Bucerotidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	33	18	54.55	24.30	5.70	6.06 - 45.5	<0.001
II	32	7	21.88	23.00	5.70	6.25 - 46.9	0.872
II/III	10	1	10.00	11.20	9.60	0 - 50	0.458
III	2	0	0.00	8.99	20.0	0 - 100	0.210
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	8	0	0.00	10.70	11.00	0 - 62.5	<0.001
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	1	0	0.00	9.04	29.00	0 - 100	0.0994
VIII	1	0	0.00	9.60	29.00	0 - 100	0.106
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 1M. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Tytonidae, Trogonidae and Bucerotidae.



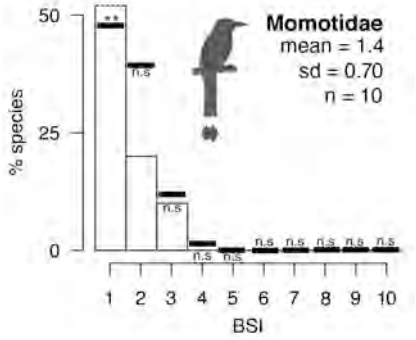
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	28.00	20.00	6.40	0 - 44	0.105
2	40.00	36.00	9.40	0 - 75	0.407
3	20.00	29.00	8.80	0 - 70	0.127
4	4.00	12.00	5.70	0 - 38	0.027
5	4.00	2.60	3.00	0 - 17	0.622
6	0.00	0.31	1.10	0 - 9.1	0.928
7	4.00	0.02	0.28	0 - 5	0.003
8	0.00	0.00	0.06	0 - 4.3	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Meropidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	14	4	28.57	9.09	6.90	0 - 42.9	0.001
II	17	2	11.76	12.40	6.90	0 - 41.2	0.541
II/III	11	0	0.00	7.18	7.30	0 - 36.4	<0.001
III	4	0	0.00	4.80	11.00	0 - 75	0.222
IV	4	0	0.00	4.67	10.00	0 - 75	0.214
V	4	1	25.00	4.64	10.00	0 - 75	0.008
VI	2	0	0.00	4.30	14.00	0 - 100	0.092
VII	2	0	0.00	4.33	14.00	0 - 100	0.093
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	41.70	22.00	9.50	0 - 50	0.004
2	25.00	37.00	14.00	0 - 83	0.148
3	8.33	28.00	12.00	0 - 80	0.016
4	16.70	10.00	7.80	0 - 40	0.250
5	8.33	2.10	4.00	0 - 20	0.128
6	0.00	0.21	1.40	0 - 10	0.976
7	0.00	0.01	0.32	0 - 10	0.999
8	0.00	0.00	0.09	0 - 9.1	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

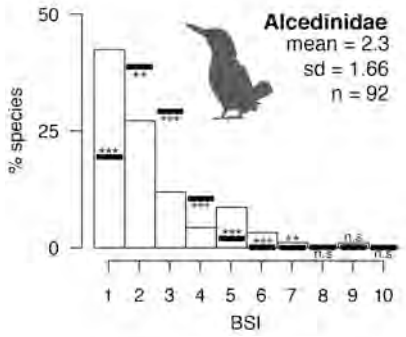
Biome	Coraciidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	6	2	33.33	7.92	10.00	0 - 50	0.002
II	9	3	33.33	15.50	10.00	0 - 55.6	0.011
II/III	5	0	0.00	6.69	11.00	0 - 60	0.443
III	1	0	0.00	4.26	20.00	0 - 100	0.045
IV	1	0	0.00	4.37	20.00	0 - 100	0.046
V	2	0	0.00	4.68	15.00	0 - 100	0.101
VI	2	0	0.00	4.79	15.00	0 - 100	0.105
VII	1	0	0.00	4.20	20.00	0 - 100	0.044
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	70.00	48.00	14.00	0 - 80	0.007
2	20.00	39.00	16.00	0 - 100	0.099
3	10.00	12.00	10.00	0 - 67	0.417
4	0.00	1.50	4.20	0 - 29	0.882
5	0.00	0.08	1.00	0 - 17	0.994
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

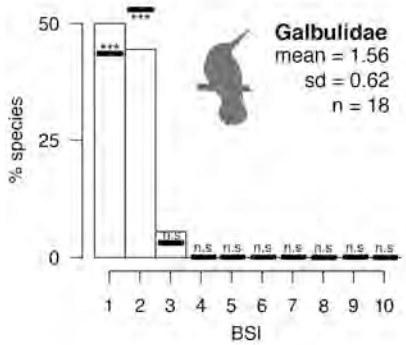
Biome	Momotidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	6	4	66.67	38.80	15.00	0 - 100	0.006
II	4	2	50.00	26.00	19.00	0 - 100	0.030
II/III	1	0	0.00	17.30	38.00	0 - 100	0.209
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	2	1	50.00	19.50	27.00	0 - 100	0.029
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	1	0	0.00	17.10	38.00	0 - 100	0.206
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 1N. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Meropidae, Coracidae and Momotidae.



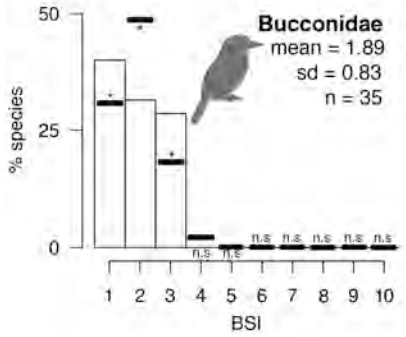
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	42.40	20.00	3.20	8 - 31	<0.001
2	27.20	39.00	4.90	20 - 58	0.009
3	12.00	29.00	4.40	12 - 47	<0.001
4	4.35	10.00	2.70	2.2 - 22	0.005
5	8.70	1.90	1.30	0 - 8.9	0.000
6	3.26	0.18	0.44	0 - 3.4	0.000
7	1.09	0.01	0.10	0 - 1.2	0.007
8	0.00	0.00	0.02	0 - 1.1	1.000
9	1.09	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Alcedinidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	76	32	42.11	15.00	3.20	3.95-28.9	<0.001
II	55	5	9.09	6.46	2.90	0 - 18.2	0.130
II/III	24	0	0.00	3.51	3.60	0 - 20.8	<0.001
III	4	0	0.00	2.71	8.00	0 - 75	0.118
IV	9	0	0.00	2.92	5.60	0 - 33.3	0.308
V	27	2	7.41	3.65	3.50	0 - 18.5	0.073
VI	10	0	0.00	2.89	5.20	0 - 30	0.349
VII	5	0	0.00	2.67	7.20	0 - 60	0.145
VIII	2	0	0.00	2.64	11.00	0 - 100	0.055
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	50.00	44.00	5.00	35 - 50	<0.001
2	44.40	54.00	6.80	44 - 65	<0.001
3	5.56	3.00	2.90	0 - 5.9	0.325
4	0.00	0.00	0.00	0 - 0	1.000
5	0.00	0.00	0.00	0 - 0	1.000
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

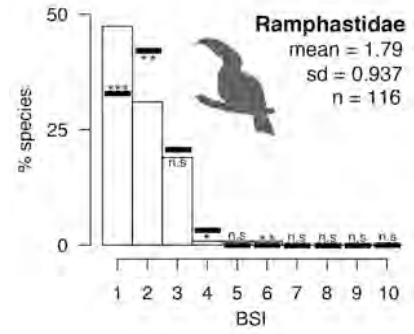
Biome	Galbulidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	17	8	47.06	41.90	4.00	35.3 - 47.1	<0.001
II	10	1	10.00	5.21	5.00	0 - 10	<0.001
II/III	1	0	0.00	2.50	16.00	0 - 100	0.026
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	0	0	0.00	0.00	0.00	0 - 0	1.000
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	40.00	31.00	4.90	12 - 49	0.014
2	31.40	49.00	8.20	17 - 82	0.011
3	28.60	19.00	4.90	0 - 36	0.019
4	0.00	2.00	2.20	0 - 12	0.459
5	0.00	0.04	0.35	0 - 3	0.985
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

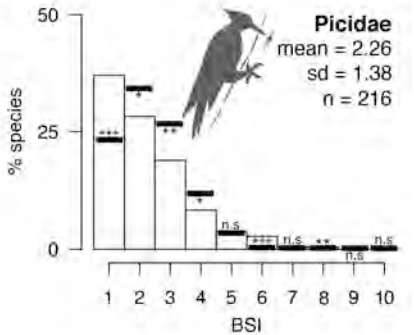
Biome	Bucconidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	33	13	39.39	29.20	4.80	12.1 - 45.5	0.005
II	19	1	5.26	3.66	3.50	0 - 10.5	0.133
II/III	4	0	0.00	1.83	6.70	0 - 50	0.078
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	9	0	0.00	2.24	4.70	0 - 22.2	0.239
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	1	0	0.00	1.63	13.00	0 - 100	0.017
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 1O. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Alcedinidae, Galbulidae and Bucconidae.



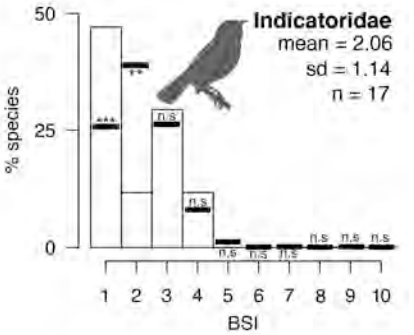
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	47.40	33.00	3.40	22 - 45	<0.001
2	31.00	42.00	4.70	25 - 58	0.008
3	19.00	21.00	3.30	10 - 33	0.390
4	0.86	3.40	1.60	0 - 11	0.015
5	0.86	0.21	0.44	0 - 2.9	0.261
6	0.86	0.01	0.08	0 - 0.98	0.007
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Ramphastidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	69	25	36.23	20.1	3.9	5.8 - 34.8	<0.001
II	66	18	27.27	18.9	4	4.55 - 33.3	0.012
II/III	12	1	8.333	9.06	8.2	0 - 50	0.431
III	2	0	0	8.46	20	0 - 100	0.194
IV	1	0	0	8.92	29	0 - 100	0.098
V	49	9	18.37	14.1	4.4	0 - 32.7	0.133
VI	1	0	0	9.04	29	0 - 100	0.099
VII	2	0	0	7.93	19	0 - 100	0.178
VIII	6	2	33.33	8.71	11	0 - 66.7	0.001
IX	0	0	0	0	0	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	37.00	23.00	2.30	15 - 32	<0.001
2	28.20	34.00	3.20	21 - 47	0.035
3	19.00	27.00	3.00	17 - 38	0.004
4	8.33	12.00	2.00	5 - 21	0.032
5	3.70	3.30	1.20	0 - 8.2	0.538
6	2.78	0.54	0.50	0 - 2.9	<0.001
7	0.46	0.06	0.17	0 - 1.5	0.121
8	0.46	0.00	0.04	0 - 0.51	0.006
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

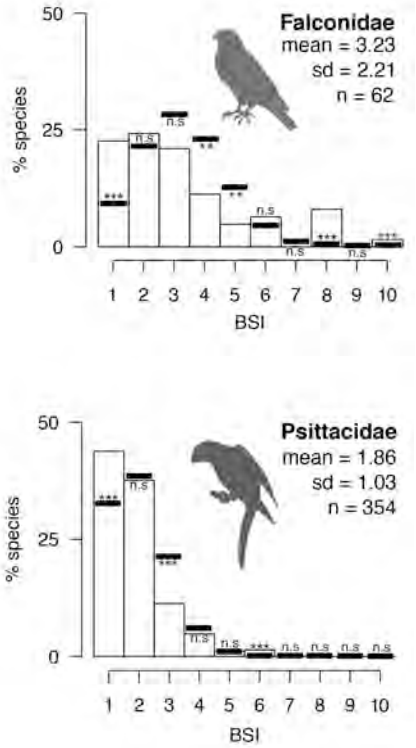
Biome	Picidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	115	41	35.65	12.60	2.80	2.61-22.6	<0.001
II	102	16	15.69	11.10	2.80	2.94-25.5	0.042
II/III	44	5	11.36	7.34	3.90	0 - 25	0.107
III	12	3	25.00	6.35	7.00	0 - 41.7	0.005
IV	16	1	6.25	6.43	6.10	0 - 37.5	0.381
V	82	8	9.76	9.49	3.10	0 - 22	0.588
VI	35	1	2.86	7.03	4.20	0 - 25.7	0.077
VII	37	2	5.41	7.07	4.10	0 - 24.3	0.979
VIII	43	3	6.98	7.31	3.90	0 - 25.6	0.648
IX	2	0	0.00	6.11	17.00	0 - 100	0.133



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	47.10	26.00	8.50	0 - 53	0.002
2	11.80	39.00	12.00	0 - 82	0.005
3	29.40	26.00	9.90	0 - 64	0.528
4	11.80	8.10	6.00	0 - 43	0.464
5	0.00	1.10	2.60	0 - 20	0.828
6	0.00	0.08	0.70	0 - 7.7	0.988
7	0.00	0.00	0.07	0 - 7.1	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Indicatoridae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	9	5	55.56	13.00	10.00	0 - 55.6	<0.001
II	10	2	20.00	14.90	9.80	0 - 60	0.172
II/III	4	0	0.00	8.08	13.00	0 - 75	0.415
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	2	0	0.00	6.58	17.00	0 - 100	0.147
V	8	1	12.50	11.60	10.00	0 - 50	0.292
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	1	0	0.00	6.99	25.00	0 - 100	0.075
VIII	1	0	0.00	6.16	24.00	0 - 100	0.066
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 1P. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Ramphastidae, Picidae and Indicatoridae.



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	22.60	9.10	3.20	0 - 23	<0.001
2	24.20	21.00	4.60	6.6 - 37	0.329
3	21.00	28.00	5.80	6.7 - 52	0.104
4	11.30	23.00	5.20	6.6 - 44	0.005
5	4.84	13.00	3.80	0 - 28	0.006
6	6.45	4.60	2.50	0 - 15	0.325
7	0.00	1.10	1.30	0 - 8.3	0.494
8	8.06	0.17	0.52	0 - 4.9	<0.001
9	0.00	0.01	0.14	0 - 1.7	0.993
10	1.61	0.00	0.04	0 - 1.7	<0.001

Biome	Falconidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	26	5	19.23	2.86	3.20	0 - 19.2	<0.001
II	37	2	5.41	4.12	3.10	0 - 16.2	0.228
II/III	28	1	3.57	2.91	3.10	0 - 17.9	0.240
III	19	2	10.53	2.41	3.50	0 - 21.1	0.009
IV	15	1	6.67	2.20	3.70	0 - 26.7	0.042
V	21	0	0.00	2.43	3.30	0 - 23.8	0.703
VI	17	0	0.00	2.29	3.60	0 - 23.5	0.496
VII	17	2	11.76	2.27	3.60	0 - 23.5	0.005
VIII	14	0	0.00	2.15	3.90	0 - 28.6	0.356
IX	6	1	16.67	1.80	5.40	0 - 50	0.004

BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	43.80	33.00	2.00	23 - 40	<0.001
2	37.60	39.00	2.70	29 - 50	0.540
3	11.30	21.00	2.10	14 - 30	<0.001
4	4.80	6.20	1.20	2.4 - 11	0.123
5	1.13	1.10	0.55	0 - 3.7	0.787
6	1.41	0.10	0.18	0 - 1.2	<0.001
7	0.00	0.01	0.04	0 - 0.32	0.983
8	0.00	0.00	0.01	0 - 0.31	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Psittacidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	206	85	41.26	21.70	2.40	12.6 - 31.1	<0.001
II	168	31	18.45	17.30	2.50	8.33 - 26.2	0.386
II/III	54	5	9.26	10.70	4.10	0 - 27.8	0.420
III	18	3	16.67	9.64	6.80	0 - 44.4	0.093
IV	34	10	29.41	10.00	5.10	0 - 32.4	<0.001
V	101	9	8.91	12.70	3.20	1.98 - 25.7	0.092
VI	29	5	17.24	9.92	5.40	0 - 37.9	0.061
VII	9	4	44.44	9.28	9.60	0 - 55.6	<0.001
VIII	36	3	8.33	10.20	4.90	0 - 36.1	0.370
IX	4	0	0.00	9.12	14.00	0 - 100	0.464

Figure 2-figure supplement 1Q. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species. in this plate: Falconidae and Psittacidae.

Appendix 2.8.4. Supplementary data of Figure 2 (Fig. S2 from A to O) – Non migratory species (fam > 10 spp)

BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	48.90	32.00	5.50	10 - 52	<0.001
2	29.80	38.00	7.50	11 - 67	0.149
3	10.60	22.00	5.80	2.3 - 54	0.017
4	8.51	6.40	3.40	0 - 25	0.375
5	2.13	0.90	1.40	0 - 10	0.484
6	0.00	0.05	0.34	0 - 2.6	0.979
7	0.00	0.00	0.05	0 - 2.4	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Tinamidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	25	9	36.00	20.40	6.90	0 - 48	0.008
II	20	3	15.00	16.70	7.60	0 - 50	0.783
II/III	13	3	23.08	13.30	8.90	0 - 53.8	0.079
III	1	0	0.00	9.96	30.00	0 - 100	0.111
IV	1	0	0.00	9.66	30.00	0 - 100	0.107
V	14	2	14.29	13.60	8.60	0 - 57.1	0.402
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	11	6	54.55	12.40	9.40	0 - 54.5	<0.001
VIII	2	0	0.00	9.69	21.00	0 - 100	0.226
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

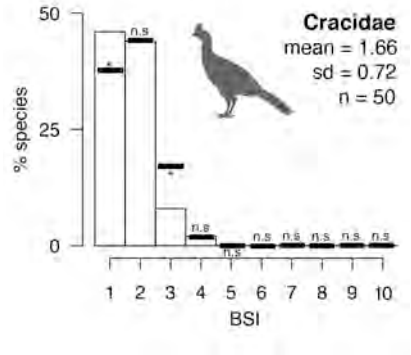
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	26.00	12.00	3.90	0 - 29	<0.001
2	18.00	25.00	5.60	6.1 - 46	0.091
3	20.00	30.00	6.60	8.2 - 60	0.062
4	18.00	21.00	5.40	4 - 43	0.368
5	12.00	9.30	3.60	0 - 24	0.327
6	4.00	2.70	2.20	0 - 13	0.459
7	0.00	0.51	1.00	0 - 8.5	0.775
8	2.00	0.05	0.32	0 - 4.3	0.020
9	0.00	0.004	0.09	0 - 2.1	0.998
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Anatidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	22	2	9.09	4.14	4.10	0 - 22.7	0.053
II	28	3	10.71	5.21	4.00	0 - 25	0.0489
II/III	19	1	5.26	3.71	4.20	0 - 26.3	0.177
III	5	0	0.00	2.51	6.90	0 - 40	0.136
IV	15	0	0.00	3.24	4.50	0 - 26.7	0.659
V	26	0	0.00	4.69	3.90	0 - 26.9	<0.001
VI	10	1	10.00	2.9	5.30	0 - 40	0.0323
VII	9	3	33.33	2.74	5.40	0 - 33.3	<0.001
VIII	8	0	0.00	2.75	5.80	0 - 37.5	0.251
IX	5	3	60.00	2.59	7.10	0 - 60	<0.001

BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	68.40	58.00	7.20	38 - 83	0.039
2	26.30	35.00	10.00	0 - 62	0.234
3	5.26	7.00	5.00	0 - 25	0.273
4	0.00	0.64	1.90	0 - 12	0.893
5	0.00	0.02	0.37	0 - 6.2	0.996
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

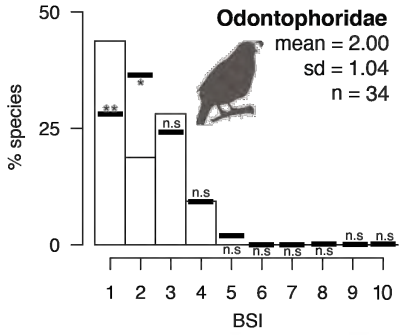
Biome	Megapodiidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	16	12	75.00	56.00	7.10	37.5 - 81.2	0.001
II	5	1	20.00	12.10	13.00	0 - 60	0.101
II/III	1	0	0.00	8.72	28.00	0 - 100	0.096
III	1	0	0.00	9.63	30.00	0 - 100	0.107
IV	1	0	0.00	9.53	29.00	0 - 100	0.105
V	2	0	0.00	9.92	21.00	0 - 100	0.236
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 2A. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Tinamidae, Anatidae and Megapodiidae.



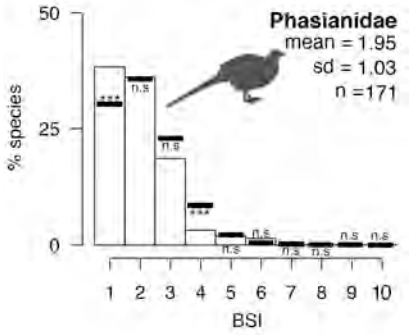
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	46.00	38.00	5.30	17 - 56	0.049
2	44.00	43.00	7.20	17 - 68	0.866
3	8.00	17.00	4.60	2.1 - 37	0.015
4	2.00	1.90	1.80	0 - 10	0.641
5	0.00	0.06	0.36	0 - 4.4	0.973
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Cracidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	33	10	30.30	27.10	5.80	6.06 - 48.5	0.261
II	27	9	33.33	20.10	6.20	0 - 44.4	0.008
II/III	4	0	0.00	10.10	15.00	0 - 75	0.530
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	16	4	25.00	13.40	7.80	0 - 50	0.039
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	3	0	0.00	9.87	17.00	0 - 100	0.366
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	44.10	29	6.30	7.1 - 53	0.005
2	20.60	37	8.60	9.4 - 66	0.030
3	26.5	24	7.00	3.1 - 54	0.511
4	8.82	8.6	4.50	0 - 30	0.890
5	0.00	1.9	2.30	0 - 15	0.535
6	0.00	0.25	0.88	0 - 7.1	0.926
7	0.00	0.02	0.23	0 - 3.7	0.995
8	0.00	0.00	0.064	0 - 3.2	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

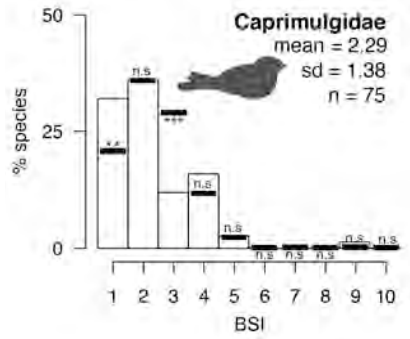
Biome	Odontophoridae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	14	7	50.00	14.30	8.60	0 - 53.8	<0.001
II	14	3	21.43	14.30	8.60	0 - 46.2	0.120
II/III	4	0	0.00	9.34	15.00	0 - 100	0.480
III	3	1	33.33	9.01	16.00	0 - 100	0.023
IV	2	0	0.00	8.71	20.00	0 - 100	0.201
V	17	4	23.53	16.70	8.00	0 - 52.9	0.126
VI	4	0	0.00	9.33	14.00	0 - 75	0.483
VII	3	0	0.00	8.99	16.00	0 - 100	0.329
VIII	7	0	0.00	10.40	11.00	0 - 71.4	<0.001
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	39.80	31.00	2.90	20 - 42	<0.001
2	35.10	36.00	3.90	22 - 53	0.751
3	19.30	23.00	3.10	11 - 36	0.174
4	2.92	8.50	2.00	1.8 - 16	<0.001
5	1.75	2.00	1.10	0 - 7.6	0.616
6	1.17	0.29	0.43	0 - 3.3	0.078
7	0.00	0.03	0.13	0 - 1.3	0.961
8	0.00	0.00	0.03	0 - 0.7	0.998
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

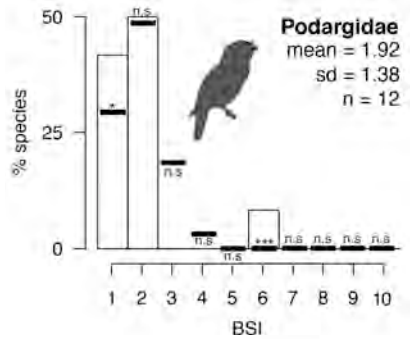
Biome	Phasianidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	46	16	34.78	13.10	4.70	0 - 34.8	<0.001
II	86	21	24.42	19.40	3.80	7 - 34.9	0.077
II/III	34	1	2.94	12.00	5.40	0 - 35.3	0.011
III	9	3	33.33	10.30	10.00	0 - 55.6	0.010
IV	13	0	0.00	10.40	8.40	0 - 53.8	<0.001
V	51	5	9.80	13.80	4.60	0 - 33.3	0.158
VI	34	2	5.88	12.10	5.40	0 - 35.3	0.071
VII	37	16	43.24	12.40	5.20	0 - 37.8	<0.001
VIII	22	3	13.64	10.90	6.50	0 - 40.9	0.257
IX	2	1	50.00	9.54	21.00	0 - 100	0.007

Figure 2-figure supplement 2B. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Craciidae, Odontophoridae and Phasianidae.



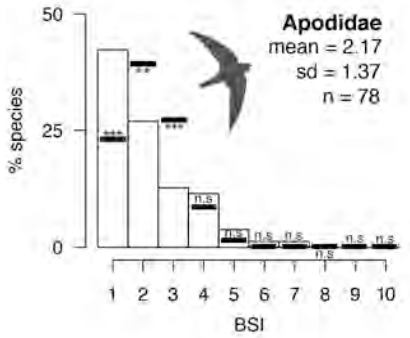
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	32.00	21.00	3.80	7.4 - 34	0.0012
2	36.00	36.00	5.40	16 - 57	0.934
3	12.00	29.00	5.00	11 - 48	<0.001
4	16.00	12.00	3.20	1.4 - 23	0.106
5	2.67	2.40	1.70	0 - 9.9	0.917
6	0.00	0.25	0.58	0 - 4.3	0.833
7	0.00	0.01	0.14	0 - 2.9	0.990
8	0.00	0.00	0.02	0 - 1.5	1.000
9	1.33	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Caprimulgidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	43	10	23.26	10.10	4.10	0 - 27.9	<0.001
II	47	8	17.02	11.60	4.10	0 - 27.7	0.065
II/III	27	4	14.81	6.87	4.60	0 - 29.6	0.029
III	4	0	0.00	4.45	10.00	0 - 75	0.200
IV	4	0	0.00	4.55	10.00	0 - 75	0.206
V	30	1	3.33	7.17	4.50	0 - 30	0.103
VI	3	0	0.00	4.54	12.00	0 - 66.7	0.151
VII	5	1	20.00	4.69	9.50	0 - 80	0.020
VIII	9	0	0.00	4.93	7.10	0 - 44.4	0.584
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	41.70	29.00	8.70	0 - 50	0.020
2	50.00	49.00	14.00	8.3 - 92	0.712
3	0.00	18.00	9.20	0 - 45	0.057
4	0.00	3.20	4.60	0 - 18	0.652
5	0.00	0.31	1.60	0 - 9.1	0.964
6	8.33	0.01	0.32	0 - 9.1	<0.001
7	0.00	0.00	0.09	0 - 9.1	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

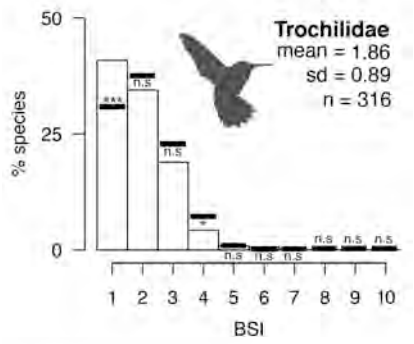
Biome	Podargidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	11	5	45.45	27.00	8.50	0 - 45.5	<0.001
II	7	0	0.00	5.40	6.90	0 - 14.3	0.608
II/III	1	0	0.00	2.50	16.00	0 - 100	0.026
III	1	0	0.00	2.77	16.00	0 - 100	0.029
IV	1	0	0.00	2.42	15.00	0 - 100	0.025
V	1	0	0.00	2.25	15.00	0 - 100	0.023
VI	1	0	0.00	2.40	15.00	0 - 100	0.025
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	42.30	23.00	3.70	8.2 - 37	<0.001
2	26.90	39.00	5.40	19 - 62	0.009
3	12.80	27.00	4.70	11 - 46	<0.001
4	11.50	8.70	2.80	0 - 21	0.198
5	3.85	1.40	1.30	0 - 7	0.089
6	1.28	0.13	0.40	0 - 2.8	0.099
7	1.28	0.01	0.10	0 - 1.4	0.006
8	0.00	0.00	0.01	0 - 1.3	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

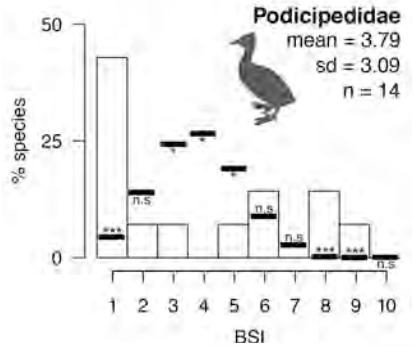
Biome	Apodidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	55	19	34.55	14.70	3.90	1.82 -32.7	<0.001
II	48	6	12.50	11.30	3.90	0 - 27.1	0.374
II/III	14	1	7.14	5.32	5.90	0 - 42.9	0.203
III	4	1	25.00	4.60	10.00	0 - 75	0.012
IV	5	0	0.00	4.57	9.20	0 - 60	0.268
V	28	5	17.86	6.80	4.50	0 - 28.6	0.006
VI	2	0	0.00	4.42	15.00	0 - 100	0.094
VII	7	1	14.29	4.71	7.90	0 - 42.9	0.038
VIII	6	0	0.00	4.64	8.50	0 - 50	0.333
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 2C. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Caprimulgidae, Podargidae and Apodidae.



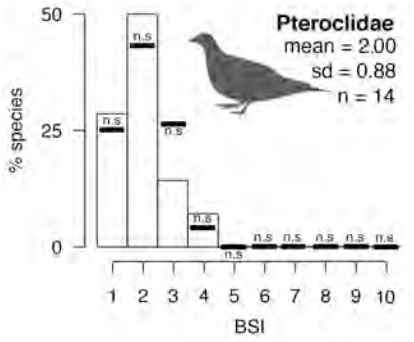
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	41.80	32.00	2.10	24 - 41	<0.001
2	35.10	38.00	2.80	29 - 50	0.149
3	19.00	22.00	2.20	14 - 30	0.084
4	3.48	6.40	1.30	2.4 - 11	0.009
5	0.63	0.89	0.54	0 - 3.5	0.363
6	0.00	0.05	0.14	0 - 1.1	0.858
7	0.00	0.001	0.02	0 - 0.35	0.998
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Trochilidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	157	41	26.11	18.70	2.70	8.92 - 28.7	0.003
II	123	21	17.07	15.40	2.90	4.88 - 27.6	0.305
II/III	29	2	6.90	10.40	5.60	0 - 37.9	0.218
III	7	3	42.86	9.67	11.00	0 - 71.4	0.002
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	146	33	22.60	17.50	2.80	6.85 - 27.4	0.025
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	58	26	44.83	11.60	4.00	0 - 31	<0.001
VIII	68	6	8.82	12.00	3.80	0 - 27.9	0.166
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	42.90	4.70	5.20	0 - 29	<0.001
2	7.14	14.00	8.10	0 - 50	0.105
3	7.14	24.00	11.00	0 - 71	0.019
4	0.00	26.00	12.00	0 - 77	0.015
5	7.14	19.00	9.70	0 - 62	0.048
6	14.30	8.90	6.80	0 - 46	0.134
7	0.00	2.80	4.10	0 - 23	0.662
8	14.30	0.50	1.90	0 - 14	<0.001
9	7.14	0.06	0.65	0 - 7.7	0.001
10	0.00	0.001	0.11	0 - 8.3	1.000

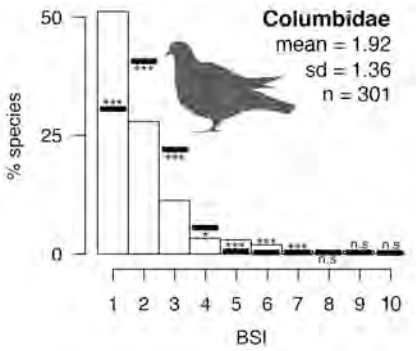
Biome	Podicipedidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	4	0	0.00	0.86	4.60	0 - 50	0.036
II	5	1	20.00	1.04	4.50	0 - 40	<0.001
II/III	7	0	0.00	1.33	4.30	0 - 28.6	0.100
III	4	0	0.00	0.91	4.70	0 - 50	0.038
IV	5	0	0.00	0.99	4.40	0 - 40	0.051
V	8	1	12.50	1.57	4.30	0 - 25	0.004
VI	6	0	0.00	1.31	4.60	0 - 33.3	0.084
VII	8	3	37.50	1.57	4.30	0 - 37.5	<0.001
VIII	5	1	20.00	1.02	4.50	0 - 40	<0.001
IX	1	0	0.00	0.63	7.90	0 - 100	0.006



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	28.60	25.00	9.00	0 - 57	0.464
2	50.00	44.00	14.00	0 - 92	0.391
3	14.30	26.00	10.00	0 - 73	0.062
4	7.14	4.60	5.00	0 - 27	0.508
5	0.00	0.22	1.30	0 - 9.1	0.972
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

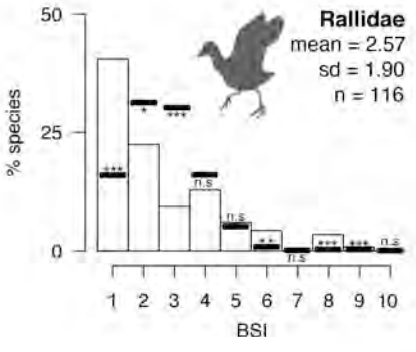
Biome	Pteroclidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	9	0	0.00	13.10	9.40	0 - 44.4	<0.001
II/III	10	0	0.00	16.10	9.30	0 - 50	<0.001
III	6	2	33.33	8.04	10.00	0 - 50	0.004
IV	1	0	0.00	5.03	22.00	0 - 100	0.053
V	0	0	0.00	0.00	0.00	0 - 0	1.000
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	2	2	100	5.42	16.00	0 - 100	<0.001
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 2D. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Trochilidae, Podicipedidae and Pteroclidae.



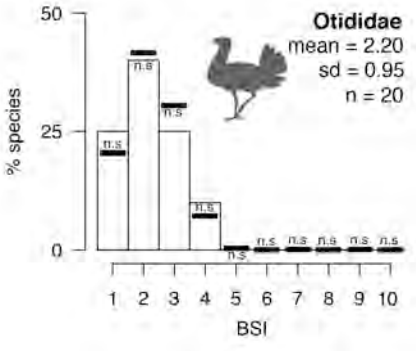
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	51.20	31.00	2.00	23 - 38	<0.001
2	27.90	41.00	2.90	31 - 52	<0.001
3	11.30	22.00	2.20	14 - 30	<0.001
4	3.32	5.80	1.20	1.4 - 11	0.019
5	2.99	0.81	0.51	0 - 3.2	<0.001
6	1.99	0.07	0.15	0 - 1.4	<.0.001
7	0.66	0.00	0.03	0 - 0.37	<0.001
8	0.00	0.00	0.01	0 - 0.35	1.000
9	0.66	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Columbidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	209	103	49.28	22.30	2.30	14.4 - 31.6	<0.001
II	155	35	22.58	14.00	2.40	6.45 - 24.5	<0.001
II/III	46	2	4.35	8.11	3.90	0 - 23.9	0.110
III	21	2	9.52	7.28	5.60	0 - 33.3	0.234
IV	16	0	0.00	7.18	6.40	0 - 43.8	<0.001
V	85	8	9.41	9.55	3.00	0 - 22.4	0.745
VI	13	0	0.00	7.06	7.00	0 - 38.5	<0.001
VII	18	4	22.22	7.33	6.10	0 - 38.9	0.0078
VIII	12	0	0.00	7.13	7.40	0 - 41.7	<0.001
IX	2	0	0.00	6.55	18.00	0 - 100	0.145



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	40.50	16.00	2.80	5.6 - 26	<0.001
2	22.40	32.00	4.10	16 - 48	0.015
3	9.48	30.00	4.30	12 - 48	<0.001
4	12.90	16.00	3.10	5.3 - 30	0.175
5	6.03	5.00	1.90	0 - 13	0.455
6	4.31	0.94	0.87	0 - 5.5	0.0018
7	0.00	0.10	0.30	0 - 2.7	0.891
8	3.45	0.01	0.08	0 - 0.93	<0.001
9	0.86	0.00	0.02	0 - 0.89	<0.001
10	0.00	0.00	0.00	0 - 0	1.000

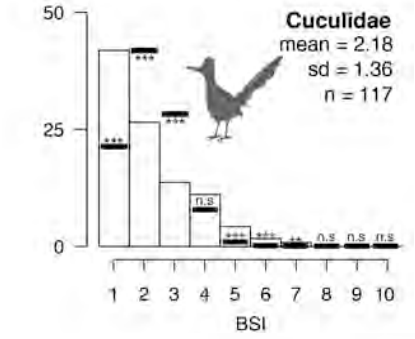
Biome	Rallidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	75	24	32.00	8.81	2.90	0 - 21.3	<0.001
II	68	11	16.18	7.52	2.90	0 - 19.1	0.0018
II/III	31	0	0.00	4.23	3.50	0 - 22.6	<0.001
III	8	0	0.00	3.33	6.20	0 - 37.5	0.316
IV	20	0	0.00	3.88	4.20	0 - 30	<0.001
V	47	6	12.77	5.23	3.10	0 - 23.4	0.0085
VI	18	1	5.56	3.67	4.40	0 - 27.8	0.168
VII	18	4	22.22	3.62	4.30	0 - 27.8	<0.001
VIII	12	0	0.00	3.46	5.20	0 - 33.3	0.532
IX	1	1	100	3.25	18.00	0 - 100	<0.001



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	25.00	20.00	6.70	0 - 50	0.233
2	40.00	42.00	11.00	0 - 85	0.641
3	25.00	30.00	8.80	5 - 67	0.259
4	10.00	7.20	5.00	0 - 28	0.365
5	0.00	0.48	1.50	0 - 11	0.909
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

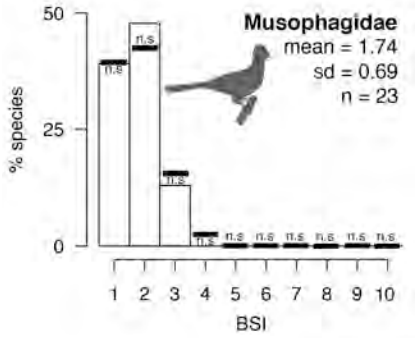
Biome	Otididae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	10	0	0.00	4.90	6.20	0 - 30	0.738
II/III	17	3	17.65	16.1	6.90	0 - 47.1	0.333
III	11	1	9.09	5.41	6.10	0 - 27.3	0.106
IV	4	1	25.00	2.93	8.30	0 - 75	0.0037
V	2	0	0.00	2.67	11.00	0 - 100	0.0563
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 2E. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Columbidae, Rallidae and Otididae.



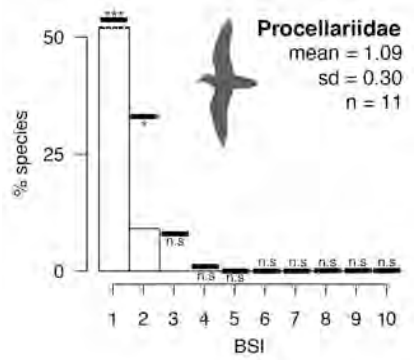
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	41.90	21.00	2.90	8.9 - 32	<0.001
2	26.50	42.00	4.40	25 - 59	<0.001
3	13.70	28.00	3.70	16 - 42	<0.001
4	11.10	7.80	2.10	0.86 - 16	0.066
5	4.27	0.90	0.83	0 - 5.4	<0.001
6	1.71	0.05	0.21	0 - 1.8	<0.001
7	0.86	0.001	0.034	0 - 0.91	0.001
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Cuculidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	93	37	39.78	15.20	2.90	4.3 - 25.8	<0.001
II	76	9	11.84	8.86	2.70	1.32 - 19.7	0.103
II/III	33	2	6.061	4.29	3.40	0 - 21.2	0.191
III	4	0	0.00	3.20	8.80	0 - 75	0.139
IV	6	0	0.00	3.23	7.20	0 - 50	0.219
V	33	1	3.03	4.37	3.40	0 - 21.2	0.762
VI	7	0	0.00	3.31	6.80	0 - 57.1	0.266
VII	2	0	0.00	3.30	13.00	0 - 100	0.070
VIII	1	0	0.00	3.26	18.00	0 - 100	0.034
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	39.10	40.00	6.40	18 - 61	0.990
2	47.80	43.00	10.00	8.7 - 82	0.323
3	13.00	16.00	5.90	0 - 38	0.270
4	0.00	2.00	2.70	0 - 18	0.622
5	0.00	0.00	0.00	0 - 0	1.000
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

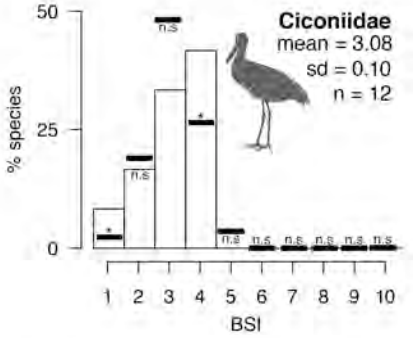
Biome	Musophagidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	6	1	16.67	4.59	8.10	0 - 33.3	0.018
II	21	7	33.33	38.00	6.50	14.3 - 61.9	0.150
II/III	6	1	16.67	4.56	8.00	0 - 33.3	0.017
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	7	0	0.00	4.72	7.40	0 - 28.6	0.442
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	90.90	58.00	15.00	0 - 91	<0.001
2	9.09	33.00	16.00	0 - 100	0.029
3	0.00	7.90	9.00	0 - 60	0.493
4	0.00	0.86	3.40	0 - 33	0.940
5	0.00	0.04	0.73	0 - 17	0.998
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

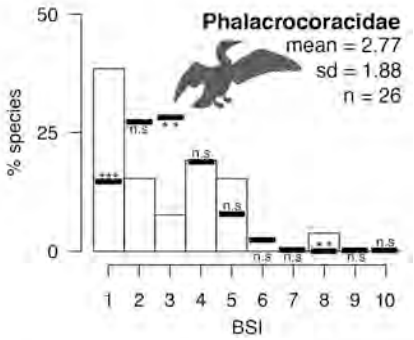
Biome	Procellariidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	5	5	100	49.10	19.00	0 - 100	<0.001
II	1	1	100	29.50	46.00	0 - 100	<0.001
II/III	0	0	0.00	0.00	0.00	0 - 0	1.000
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	3	2	66.67	37.00	26.00	0 - 100	0.034
VI	2	1	50.00	32.80	32.00	0 - 100	0.105
VII	1	1	100	29.40	46.00	0 - 100	<0.001
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 2F. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Cuculidae, Musophagidae and Procellariidae.



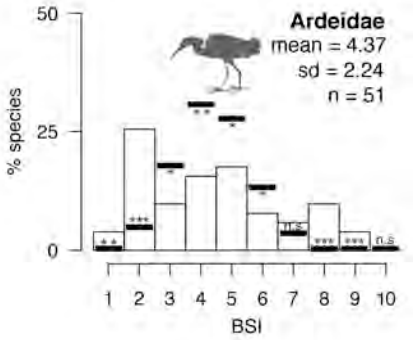
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	8.33	2.80	4.30	0 - 17	0.022
2	16.70	19.00	8.70	0 - 42	0.772
3	33.30	48.00	13.00	8.3 - 92	0.086
4	41.70	26.00	9.60	0 - 55	0.017
5	0.00	3.50	4.70	0 - 18	0.611
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Ciconiidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	10	1	10.00	0.78	2.70	0 - 10	<0.001
II	11	0	0.00	1.58	3.60	0 - 18.2	0.203
II/III	10	0	0.00	0.75	2.60	0 - 10	0.082
III	2	0	0.00	0.13	2.50	0 - 50	0.003
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	4	0	0.00	0.185	2.10	0 - 25	0.007
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	38.50	15.00	5.90	0 - 38	<0.001
2	15.40	27.00	8.20	0 - 58	0.055
3	7.69	28.00	8.90	0 - 67	0.002
4	19.20	19.00	7.10	0 - 43	0.792
5	15.40	8.10	4.90	0 - 32	0.095
6	0.00	2.40	2.90	0 - 16	0.525
7	0.00	0.42	1.30	0 - 8.7	0.899
8	3.85	0.05	0.45	0 - 4.5	0.010
9	0.00	0.00	0.09	0 - 4	1.000
10	0.00	0.00	0.00	0 - 0	1.000

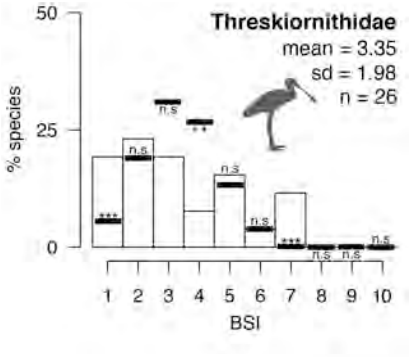
Biome	Phalacrocoracidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	13	1	7.69	1.35	3.10	0 - 15.4	0.007
II	16	0	0.00	2.64	3.80	0 - 25	0.579
II/III	14	0	0.00	1.57	3.20	0 - 21.4	0.263
III	3	0	0.00	0.51	4.10	0 - 33.3	0.016
IV	2	0	0.00	0.37	4.30	0 - 50	0.007
V	7	0	0.00	0.64	3.00	0 - 28.6	0.046
VI	3	0	0.00	0.55	4.20	0 - 33.3	0.017
VII	3	0	0.00	0.39	3.60	0 - 33.3	0.012
VIII	1	0	0.00	0.44	6.60	0 - 100	0.004
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	3.92	0.55	1.00	0 - 5.9	0.001
2	25.50	5.20	2.80	0 - 18	<0.001
3	9.80	18.00	4.60	3.9 - 33	0.012
4	15.70	31.00	6.30	7.8 - 59	0.004
5	17.60	28.00	5.90	7.8 - 49	0.027
6	7.84	14.00	4.10	0 - 27	0.046
7	5.88	3.50	2.30	0 - 14	0.088
8	9.80	0.42	0.88	0 - 5.9	<0.001
9	3.92	0.01	0.16	0 - 2	<0.001
10	0.00	0.00	0.00	0 - 0	1.000

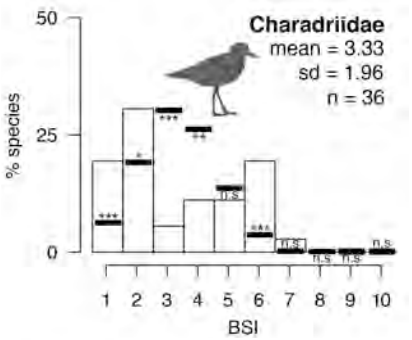
Biome	Ardeidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	41	0	0.00	0.00	0.00	0 - 0	<0.001
II	51	2	3.922	0.548	1.00	0 - 5.88	0.001
II/III	31	0	0.00	0.00	0.00	0 - 0	<0.001
III	17	0	0.00	0.00	0.00	0 - 0	<0.001
IV	17	0	0.00	0.00	0.00	0 - 0	<0.001
V	33	0	0.00	0.00	0.00	0 - 0	<0.001
VI	21	0	0.00	0.00	0.00	0 - 0	<0.001
VII	9	0	0.00	0.00	0.00	0 - 0	<0.001
VIII	3	0	0.00	0.00	0.00	0 - 0	<0.001
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 2G. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Ciconiidae, Phalacrocoracidae and Ardeidae.



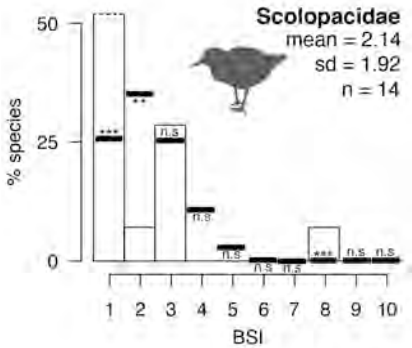
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	19.20	5.60	3.90	0 - 23	<0.001
2	23.10	19.00	6.50	0 - 46	0.252
3	19.20	31.00	8.80	3.8 - 65	0.063
4	7.69	27.00	8.30	0 - 58	0.0025
5	15.40	13.00	5.70	0 - 35	0.347
6	3.85	3.70	3.40	0 - 20	0.423
7	11.50	0.54	1.40	0 - 12	<0.001
8	0.00	0.04	0.40	0 - 4.2	0.989
9	0.00	<0.001	0.04	0 - 3.8	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Threskiornithidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	12	1	8.33	0.89	2.60	0 - 16.7	0.003
II	23	2	8.67	4.01	3.80	0 - 17.4	0.047
II/III	15	0	0.00	1.05	2.60	0 - 20	0.176
III	6	0	0.00	0.52	2.90	0 - 33.3	0.032
IV	8	1	12.50	0.701	2.90	0 - 25	0.001
V	13	0	0.00	0.91	2.60	0 - 23.1	0.130
VI	5	1	20.00	0.53	3.30	0 - 40	<0.001
VII	4	0	0.00	0.56	3.70	0 - 25	0.023
VIII	1	0	0.00	0.45	6.70	0 - 100	0.005
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	19.4	6.30	3.60	0 - 20	<0.001
2	30.6	19.00	5.60	2.8 - 42	0.015
3	5.56	30.00	7.50	2.8 - 61	<0.001
4	11.1	26.00	7.00	2.8 - 58	0.00513
5	11.1	13.00	4.90	0 - 33	0.296
6	19.4	4.00	2.90	0 - 18	<0.001
7	2.78	0.60	1.30	0 - 8.8	0.0679
8	0.00	0.04	0.32	0 - 2.9	0.987
9	0.00	<0.001	0.04	0 - 2.9	1.000
10	0.00	0.00	0.00	0 - 0	1.000

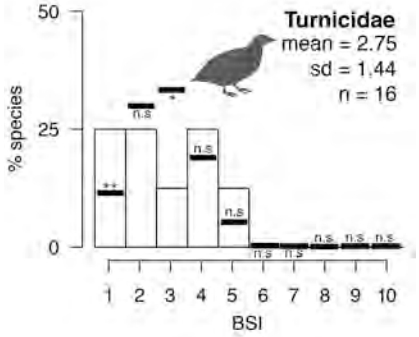
Biome	Charadriidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	13	0	0.00	1.12	2.90	0 - 23.1	0.159
II	29	3	10.34	3.73	3.30	0 - 20.7	0.012
II/III	20	0	0.00	1.64	2.80	0 - 20	0.409
III	13	0	0.00	1.17	3.00	0 - 23.1	0.166
IV	18	0	0.00	1.48	2.80	0 - 16.7	0.320
V	14	1	7.14	1.21	2.90	0 - 21.4	0.0105
VI	8	1	12.5	1.00	3.50	0 - 25	0.0022
VII	4	2	50.00	0.78	4.30	0 - 25	<0.001
VIII	1	0	0.00	0.75	8.60	0 - 100	0.008
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	57.10	26.00	9.50	0 - 57	<0.001
2	7.14	35.00	13.00	0 - 86	0.004
3	28.60	25.00	11.00	0 - 82	0.559
4	0.00	11.00	7.70	0 - 50	0.183
5	0.00	2.70	4.30	0 - 30	0.682
6	0.00	0.46	1.90	0 - 18	0.943
7	0.00	0.038	0.56	0 - 9.1	0.995
8	7.14	<0.001	0.083	0 - 8.3	<0.001
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

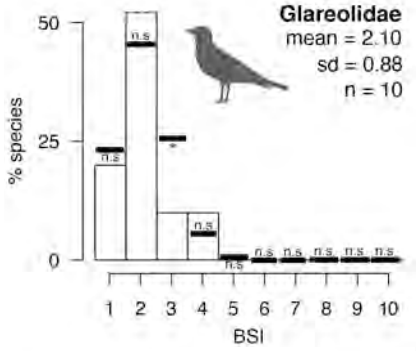
Biome	Scolopacidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	4	1	25.00	9.65	14.00	0 - 75	0.041
II	3	1	33.33	9.06	16.00	0 - 100	0.018
II/III	1	0	0.00	7.43	26.00	0 - 100	0.080
III	0	0	0.00	0	0.00	0 - 0	1.000
IV	1	0	0.00	7.59	26.00	0 - 100	0.082
V	8	3	37.50	16.1	12.00	0 - 62.5	0.012
VI	3	1	33.33	8.95	16.00	0 - 100	0.015
VII	5	1	20.00	10.8	13.00	0 - 80	0.085
VIII	4	0	0.00	9.83	14.00	0 - 75	0.536
IX	1	1	100	7.08	26.00	0 - 100	<0.001

Figure 2-figure supplement 2H. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Threskiornithidae, Charadriidae and Scolopacidae.



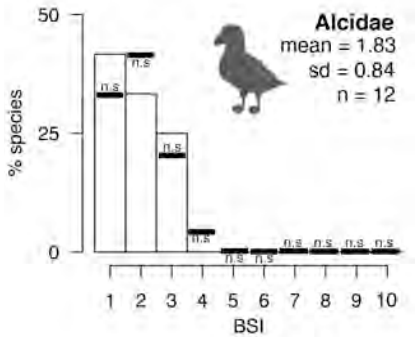
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	25.00	12.00	6.60	0 - 38	0.010
2	25.00	30.00	10.00	0 - 69	0.283
3	12.50	33.00	12.00	0 - 80	0.014
4	25.00	19.00	8.40	0 - 50	0.199
5	12.50	5.30	5.00	0 - 29	0.066
6	0.00	0.70	2.10	0 - 13	0.893
7	0.00	0.03	0.44	0 - 6.7	0.995
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Turnicidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	6	0	0.00	1.82	5.30	0 - 33.3	0.120
II	14	2	14.29	8.94	6.60	0 - 35.7	0.101
II/III	9	1	11.11	2.52	4.90	0 - 22.2	0.011
III	1	0	0.00	1.23	11.00	0 - 100	0.013
IV	5	0	0.00	1.73	5.70	0 - 40	0.092
V	6	1	16.67	1.80	5.30	0 - 33.3	0.002
VI	3	0	0.00	1.34	6.60	0 - 66.7	0.042
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	20.00	23.00	9.60	0 - 50	0.247
2	60.00	45.00	15.00	0 - 90	0.134
3	10.00	25.00	12.00	0 - 67	0.036
4	10.00	5.70	6.50	0 - 33	0.203
5	0.00	0.46	2.10	0 - 11	0.956
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

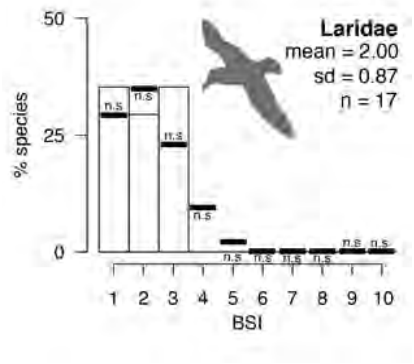
Biome	Glareolidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	2	0	0.00	2.62	11.00	0 - 50	0.055
II	9	2	22.22	20.5	9.60	0 - 44.4	0.278
II/III	6	0	0.00	5.08	7.70	0 - 16.7	0.438
III	2	0	0.00	2.49	11.00	0 - 50	0.052
IV	2	0	0.00	2.61	11.00	0 - 50	0.055
V	0	0	0.00	0.00	0.00	0 - 0	1.000
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	41.70	33	11.00	0 - 67	0.176
2	33.30	41	15.00	0 - 100	0.333
3	25.00	21	11.00	0 - 67	0.491
4	0.00	4.4	5.60	0 - 33	0.574
5	0.00	0.4	1.90	0 - 22	0.956
6	0.00	0.013	0.34	0 - 10	0.999
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

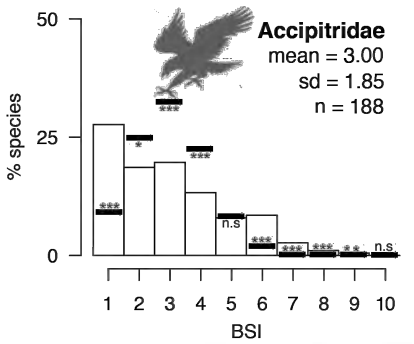
Biome	Alcidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	0	0	0.00	0.00	0.00	0 - 0	1.000
II/III	0	0	0.00	0.00	0.00	0 - 0	1.000
III	2	1	50.00	8.21	19.00	0 - 100	0.004
IV	1	0	0.00	7.49	26.00	0 - 100	0.081
V	1	0	0.00	7.40	26.00	0 - 100	0.080
VI	4	0	0.00	10.10	14.00	0 - 75	0.576
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	5	0	0.00	11.7	13.00	0 - 60	0.988
IX	9	4	44.44	27.2	11.00	0 - 66.7	0.021

Figure 2-figure supplement 2I. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Turnicidae, Glareolidae and Alcidae.



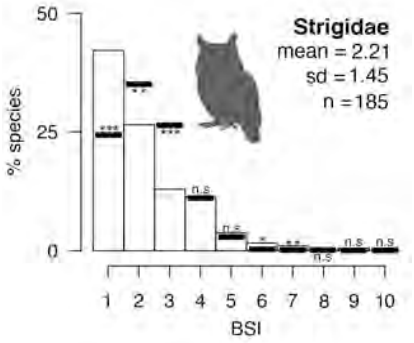
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	35.30	30.00	9.30	0 - 59	0.360
2	29.40	35.00	12.00	0 - 80	0.499
3	35.30	23.00	10.00	0 - 62	0.147
4	0.00	9.60	6.80	0 - 42	0.170
5	0.00	2.50	3.80	0 - 25	0.665
6	0.00	0.40	1.60	0 - 15	0.941
7	0.00	0.05	0.58	0 - 8.3	0.993
8	0.00	0.01	0.12	0 - 8.3	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Laridae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	6	0	0.00	14.90	14.00	0 - 66.7	<0.001
II	7	1	14.29	16.50	13.00	0 - 71.4	0.474
II/III	4	0	0.00	12.40	16.00	0 - 75	0.733
III	4	3	75.00	13.10	16.00	0 - 75	<0.001
IV	3	0	0.00	11.40	18.00	0 - 100	0.453
V	3	0	0.00	12.00	19.00	0 - 100	0.470
VI	3	0	0.00	12.10	18.00	0 - 100	0.482
VII	1	0	0.00	10.50	31.00	0 - 100	0.117
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	3	2	66.67	11.70	18.00	0 - 100	<0.001



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	27.70	9.20	1.80	2.7 - 17	<0.001
2	18.60	25.00	2.80	15 - 37	0.0139
3	19.70	32.00	3.40	19 - 44	<0.001
4	13.30	23.00	2.80	13 - 33	<0.001
5	7.98	8.70	1.80	2.1 - 16	0.462
6	8.51	1.90	0.95	0 - 6	<0.001
7	2.66	0.24	0.36	0 - 2.2	<0.001
8	1.06	0.017	0.09	0 - 1.1	<0.001
9	0.53	<0.001	0.02	0 - 0.55	0.001
10	0.00	0.00	0.00	0 - 0	1.000

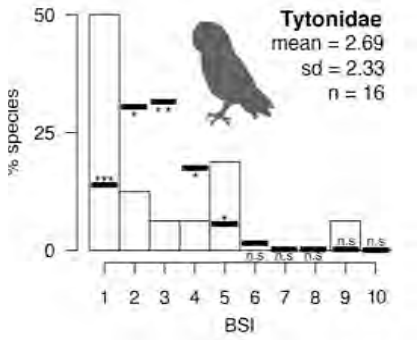
Biome	Accipitridae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	136	39	28.68	4.61	1.70	0 - 11	<0.001
II	123	4	3.25	3.68	1.60	0 - 11.4	0.959
II/III	93	2	2.15	2.53	1.60	0 - 9.68	0.729
III	30	0	0.00	1.47	2.20	0 - 16.7	0.563
IV	32	1	3.13	1.55	2.20	0 - 15.6	0.093
V	86	3	3.49	2.34	1.60	0 - 9.3	0.155
VI	17	0	0.00	1.41	2.90	0 - 23.5	0.274
VII	25	3	12.00	1.46	2.40	0 - 16	<0.001
VIII	18	0	0.00	1.40	2.80	0 - 22.2	0.290
IX	4	0	0.00	1.34	5.70	0 - 50	0.056



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	42.20	24.00	2.5	14 - 34	<0.001
2	26.50	35.00	3.5	22 - 51	0.00573
3	13.00	26.00	3.2	14 - 39	<0.001
4	11.40	11.00	2.1	3.4 - 19	0.899
5	3.78	2.90	1.2	0 - 7.6	0.287
6	1.62	0.44	0.49	0 - 2.9	0.038
7	1.08	0.04	0.15	0 - 1.7	0.002
8	0.00	0.002	0.03	0 - 0.61	0.997
9	0.54	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

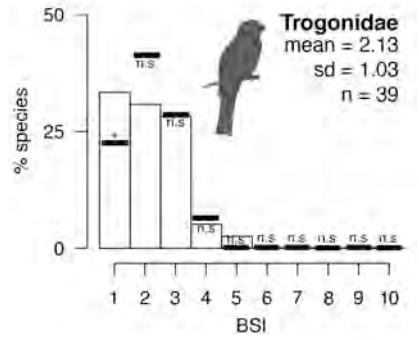
Biome	Strigidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	95	41	43.16	12.70	3.10	3.16 - 25.3	<0.001
II	93	18	19.35	12.50	3.10	2.15 - 25.8	0.0109
II/III	38	2	5.263	7.82	4.20	0 - 26.3	0.225
III	17	1	5.882	6.87	6.00	0 - 35.3	0.493
IV	16	0	0.00	6.88	6.30	0 - 43.8	<0.001
V	72	14	19.44	10.10	3.30	0 - 25	0.0031
VI	31	0	0.00	7.54	4.60	0 - 29	<0.001
VII	14	0	0.00	6.59	6.70	0 - 50	<0.001
VIII	31	2	6.452	7.44	4.60	0 - 25.8	0.714
IX	1	0	0.00	6.32	24.00	0 - 100	0.0675

Figure 2-figure supplement 2J. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Laridae, Accipitridae and Strigidae.



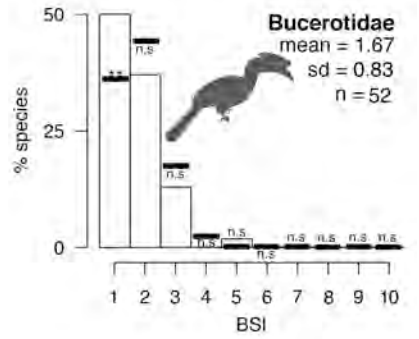
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	50.00	14.00	7.20	0 - 44	<0.001
2	12.50	30.00	11.00	0 - 69	0.024
3	6.25	31.00	12.00	0 - 80	0.003
4	6.25	18.00	8.50	0 - 50	0.030
5	18.80	5.70	5.30	0 - 29	0.016
6	0.00	1.10	2.60	0 - 14	0.837
7	0.00	0.12	0.89	0 - 13	0.981
8	0.00	0.01	0.20	0 - 6.7	0.999
9	6.25	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Tytonidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	12	6	50.00	8.92	7.30	0 - 41.7	<0.001
II	9	1	11.11	4.93	6.70	0 - 33.3	0.056
II/III	3	0	0.00	2.74	9.40	0 - 66.7	0.088
III	1	0	0.00	2.15	15.00	0 - 100	0.022
IV	2	0	0.00	2.46	11.00	0 - 100	0.051
V	7	1	14.29	3.89	7.00	0 - 57.1	0.020
VI	3	0	0.00	2.58	9.00	0 - 66.7	0.083
VII	3	0	0.00	2.66	9.20	0 - 66.7	0.085
VIII	3	0	0.00	2.79	9.50	0 - 66.7	0.089
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	33.30	23.00	5.00	5.4 - 44	0.010
2	30.80	41.00	7.80	11 - 68	0.086
3	28.20	29.00	6.20	7.7 - 53	0.729
4	5.13	6.6	3.40	0 - 26	0.291
5	2.56	0.36	0.95	0 - 5.7	0.124
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

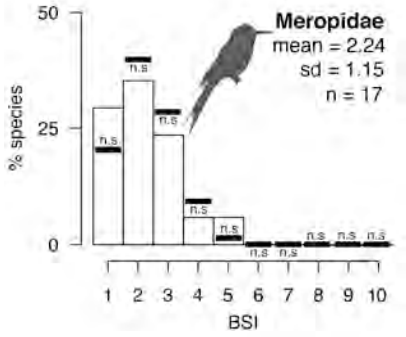
Biome	Trogonidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	30	10	33.33	15.70	5.10	0 - 36.7	<0.001
II	20	2	10.00	7.48	5.00	0 - 30	0.195
II/III	3	0	0.00	3.89	8.90	0 - 100	0.126
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	22	1	4.55	8.22	4.80	0 – 31.8	0.128
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	8	0	0.00	4.60	7.20	0 - 50	0.470
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	50.00	37.00	5.20	19 - 54	0.004
2	36.50	44.00	7.00	13 - 67	0.162
3	11.50	16.00	4.50	2 - 32	0.169
4	0.00	2.20	2.00	0 - 11	0.319
5	1.92	0.12	0.50	0 - 4.5	0.060
6	0.00	0.00	0.078	0 - 2.2	0.999
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

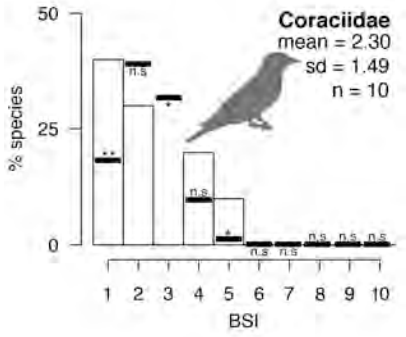
Biome	Bucerotidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	33	18	54.55	24.30	5.70	6.06 - 45.5	<0.001
II	32	7	21.88	23.00	5.70	6.25 - 46.9	0.872
II/III	10	1	10.00	11.20	9.60	0 - 50	0.458
III	2	0	0.00	8.99	20.00	0 - 100	0.210
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	8	0	0.00	10.70	11.00	0 - 62.5	<0.001
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	1	0	0.00	9.04	29.00	0 - 100	0.0994
VIII	1	0	0.00	9.60	29.00	0 - 100	0.106
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 2K. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Tytonidae, Trogonidae and Bucerotidae.



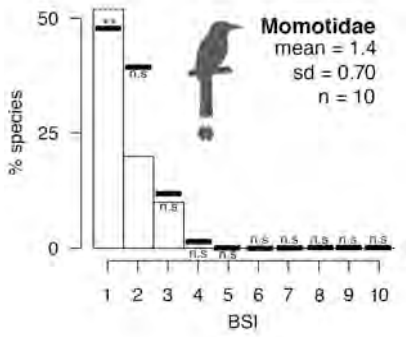
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	29.4	21.00	7.70	0 - 47	0.087
2	35.3	40.00	12.00	0 - 82	0.410
3	23.5	29.00	10.00	0 - 77	0.314
4	5.88	9.40	6.10	0 - 36	0.170
5	5.88	1.50	2.80	0 - 20	0.146
6	0.00	0.089	0.74	0 - 7.1	0.986
7	0.00	0.003	0.12	0 - 6.7	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Meropidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	11	3	27.27	9.25	7.50	0 - 36.4	0.003
II	13	2	15.38	13.80	7.90	0 - 38.5	0.305
II/III	5	0	0.00	4.48	8.90	0 - 60	0.270
III	3	0	0.00	3.98	11.00	0 - 66.7	0.133
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	4	0	0.00	4.33	10.00	0 - 75	0.198
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	1	0	0.00	3.29	18.00	0 - 100	0.034
VIII	1	0	0.00	3.50	18.00	0 - 100	0.036
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	40.00	18.00	9.60	0 - 50	0.001
2	30.00	39.00	15.00	0 - 90	0.240
3	0.00	32.00	13.00	0 - 78	0.015
4	20.00	9.80	8.00	0 - 44	0.102
5	10.00	1.20	3.40	0 - 25	0.046
6	0.00	0.05	0.73	0 - 12	0.995
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0	0.00	0.00	0 - 0	1.000

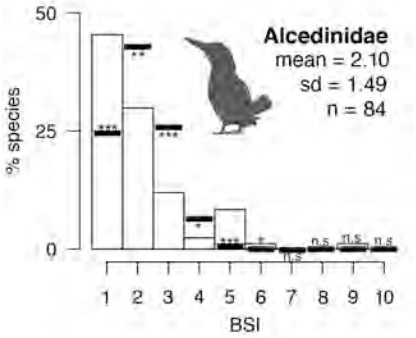
Biome	Coraciidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	6	2	33.33	7.92	10.00	0 - 50	0.002
II	9	3	33.33	15.50	10.00	0 - 55.6	0.011
II/III	5	0	0.00	6.69	11.00	0 - 60	0.443
III	1	0	0.00	4.26	20.00	0 - 100	0.045
IV	1	0	0.00	4.37	20.00	0 - 100	0.046
V	2	0	0.00	4.68	15.00	0 - 100	0.101
VI	2	0	0.00	4.79	15.00	0 - 100	0.105
VII	1	0	0.00	4.20	20.00	0 - 100	0.044
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	70.00	48.00	14.00	0 - 80	0.007
2	20.00	39.00	16.00	0 - 100	0.099
3	10.00	12.00	10.00	0 - 67	0.417
4	0.00	1.50	4.20	0 - 29	0.882
5	0.00	0.08	1.00	0 - 17	0.994
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

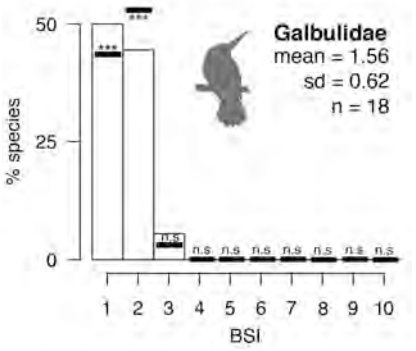
Biome	Momotidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	6	4	66.67	38.80	15.00	0 - 100	0.006
II	4	2	50.00	26.00	19.00	0 - 100	0.030
II/III	1	0	0.00	17.30	38.00	0 - 100	0.209
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	2	1	50.00	19.50	27.00	0 - 100	0.029
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	1	0	0.00	17.10	38.00	0 - 100	0.206
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 2L. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Meropidae, Coraciidae and Momotidae.



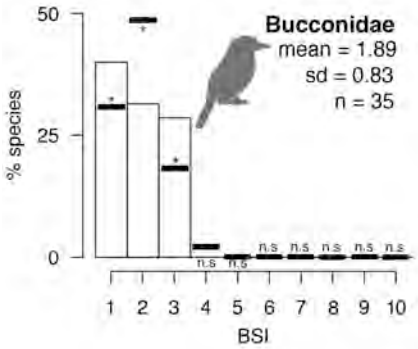
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	45.20	24.00	3.4	9.1 - 37	<0.001
2	29.80	43.00	5.3	24 - 64	0.006
3	11.90	25.00	4.2	8.4 - 45	<0.001
4	2.38	6.50	2.3	0 - 16	0.0132
5	8.33	0.78	0.94	0 - 5.1	<0.001
6	1.19	0.04	0.23	0 - 2.5	0.036
7	0.00	0.001	0.039	0 - 1.3	0.999
8	0.00	0.00	0.00	0 - 0	1.000
9	1.19	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Alcedinidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	70	31	44.29	19.60	3.50	5.71-31.4	<0.001
II	49	5	10.20	7.82	3.20	0 - 20.4	0.168
II/III	21	0	0.00	4.38	4.20	0 - 23.8	<0.001
III	3	0	0.00	3.20	10.00	0 - 66.7	0.103
IV	6	0	0.00	3.72	7.70	0 - 50	0.258
V	20	2	10.00	4.30	4.40	0 - 30	0.046
VI	4	0	0.00	3.57	9.20	0 - 75	0.157
VII	2	0	0.00	3.35	13.00	0 - 100	0.071
VIII	1	0	0.00	3.13	17.00	0 - 100	0.032
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	50.00	44.00	5.00	35 - 50	<0.001
2	44.40	54.00	6.80	44 - 65	<0.001
3	5.56	3.00	2.90	0 - 5.9	0.325
4	0.00	0.00	0.00	0 - 0	1.000
5	0.00	0.00	0.00	0 - 0	1.000
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

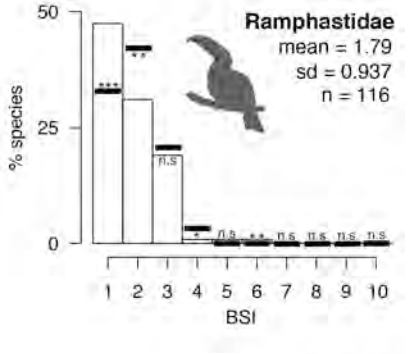
Biome	Galbulidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	17	8	47.06	41.90	4.00	35.3 - 47.1	<0.001
II	10	1	10.00	5.21	5.00	0 - 10	<0.001
II/III	1	0	0.00	2.50	16.00	0 - 100	0.026
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	0	0	0.00	0.00	0.00	0 - 0	1.000
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	0	0	0.00	0.00	0.00	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	40.00	31.00	4.90	12 - 49	0.014
2	31.40	49.00	8.20	17 - 82	0.011
3	28.60	19.00	4.90	0 - 36	0.019
4	0.00	2.00	2.20	0 - 12	0.459
5	0.00	0.04	0.35	0 - 3	0.985
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

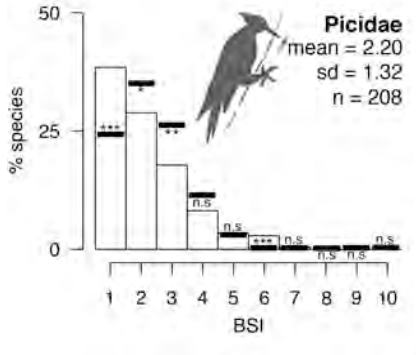
Biome	Bucconidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	33	13	39.39	29.20	4.80	12.1 - 45.5	0.005
II	19	1	5.26	3.66	3.50	0 - 10.5	0.133
II/III	4	0	0.00	1.83	6.70	0 - 50	0.078
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	9	0	0.00	2.24	4.70	0 - 22.2	0.239
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	1	0	0.00	1.63	13.00	0 - 100	0.017
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 2M. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Alcedinidae, Galbulidae and Bucconidae.



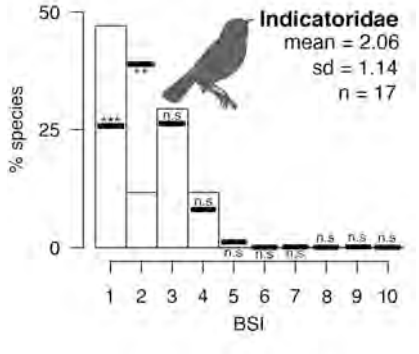
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	47.40	33.00	3.40	22 - 45	<0.001
2	31.00	42.00	4.70	25 - 58	0.008
3	19.00	21.00	3.30	10 - 33	0.390
4	0.86	3.40	1.60	0 - 11	0.015
5	0.86	0.21	0.44	0 - 2.9	0.261
6	0.86	0.01	0.08	0 - 0.98	0.007
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Ramphastidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	69	25	36.23	20.1	3.9	5.8 - 34.8	<0.001
II	66	18	27.27	18.9	4	4.55 - 33.3	0.012
II/III	12	1	8.333	9.06	8.2	0 - 50	0.431
III	2	0	0	8.46	20	0 - 100	0.194
IV	1	0	0	8.92	29	0 - 100	0.098
V	49	9	18.37	14.1	4.4	0 - 32.7	0.133
VI	1	0	0	9.04	29	0 - 100	0.099
VII	2	0	0	7.93	19	0 - 100	0.178
VIII	6	2	33.33	8.71	11	0 - 66.7	0.001
IX	0	0	0	0	0	0 - 0	1.000



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	38.5	24.00	2.40	14 - 36	<0.001
2	28.8	35.00	3.30	21 - 48	0.026
3	17.8	26.00	3.00	15 - 37	0.002
4	8.17	11.00	2.00	4.1 - 19	0.079
5	3.37	2.70	1.10	0 - 7.5	0.389
6	2.88	0.41	0.44	0 - 2.6	<0.001
7	0.48	0.04	0.13	0 - 1.6	0.069
8	0.00	0.00	0.03	0 - 0.53	0.997
9	0.00	0.00	0.005	0 - 0.52	1.000
10	0.00	0.00	0.00	0 - 0	1.000

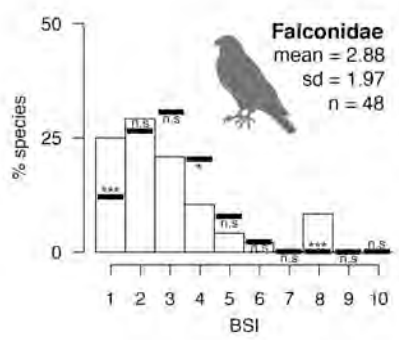
Biome	Picidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	114	41	35.96	13.60	2.80	3.51-25.4	<0.001
II	101	16	15.84	12.00	2.90	1.98-23.8	0.074
II/III	43	5	11.63	7.71	4.00	0 - 25.6	0.114
III	12	3	25.00	6.56	7.10	0 - 41.7	0.005
IV	13	1	7.69	6.61	6.90	0 - 38.5	0.272
V	80	8	10.00	9.99	3.10	0 - 22.5	0.684
VI	27	1	3.70	7.08	4.90	0 - 29.6	0.155
VII	30	2	6.67	7.20	4.60	0 - 30.0	0.578
VIII	36	3	8.33	7.50	4.30	0 - 27.8	0.391
IX	1	0	0.00	6.12	24.00	0 - 100	0.065



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	47.10	26.00	8.50	0 - 53	0.002
2	11.80	39.00	12.00	0 - 82	0.005
3	29.40	26.00	9.90	0 - 64	0.528
4	11.80	8.10	6.00	0 - 43	0.464
5	0.00	1.10	2.60	0 - 20	0.828
6	0.00	0.08	0.70	0 - 7.7	0.988
7	0.00	0.00	0.07	0 - 7.1	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

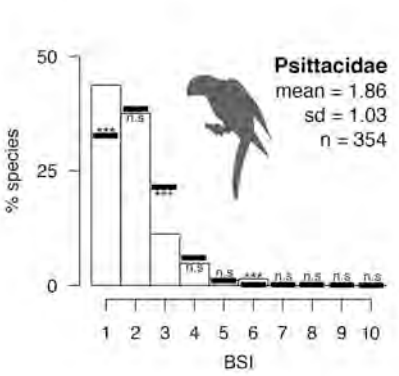
Biome	Indicatoridae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	9	5	55.56	13.00	10.00	0 - 55.6	<0.001
II	10	2	20.00	14.90	9.80	0 - 60	0.172
II/III	4	0	0.00	8.08	13.00	0 - 75	0.415
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	2	0	0.00	6.58	17.00	0 - 100	0.147
V	8	1	12.50	11.60	10.00	0 - 50	0.292
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	1	0	0.00	6.99	25.00	0 - 100	0.075
VIII	1	0	0.00	6.16	24.00	0 - 100	0.066
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

Figure 2-figure supplement 2N. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Ramphastidae, Picidae and Indicatoridae.



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	25.00	12.00	3.90	0 - 28	<0.001
2	29.20	27.00	5.80	4.3 - 51	0.453
3	20.80	30.00	6.80	8.3 - 57	0.0691
4	10.40	20.00	5.30	2.2 - 45	0.0173
5	4.17	8.20	3.50	0 - 22	0.0735
6	2.08	2.10	2.00	0 - 11	0.505
7	0.00	0.33	0.83	0 - 8.3	0.853
8	8.33	0.03	0.26	0 - 2.3	<0.001
9	0.00	0.00	0.06	0 - 2.2	0.999
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Falconidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	26	5	19.23	2.84	3.20	0 - 19.2	<0.001
II	37	2	5.41	4.09	3.10	0 - 18.9	0.227
II/III	28	1	3.57	2.98	3.10	0 - 17.9	0.251
III	19	2	10.53	2.38	3.40	0 - 21.1	0.007
IV	15	1	6.67	2.21	3.80	0 - 40	0.042
V	21	0	0.00	2.51	3.30	0 - 19	0.723
VI	17	0	0.00	2.23	3.50	0 - 17.6	0.481
VII	17	2	11.76	2.29	3.60	0 - 23.5	0.006
VIII	14	0	0.00	2.03	3.80	0 - 28.6	0.332
IX	6	1	16.67	1.79	5.40	0 - 33.3	0.004



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	43.80	33.00	2.00	23 - 40	<0.001
2	37.60	39.00	2.70	29 - 50	0.540
3	11.30	21.00	2.10	14 - 30	<0.001
4	4.80	6.20	1.20	2.4 - 11	0.123
5	1.13	1.10	0.55	0 - 3.7	0.787
6	1.41	0.10	0.18	0 - 1.2	<0.001
7	0.00	0.01	0.04	0 - 0.32	0.983
8	0.00	0.00	0.01	0 - 0.31	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Psittacidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	206	85	41.26	21.70	2.40	12.6 - 31.1	<0.001
II	168	31	18.45	17.30	2.50	8.33 - 26.2	0.386
II/III	54	5	9.26	10.70	4.10	0 - 27.8	0.420
III	18	3	16.67	9.64	6.80	0 - 44.4	0.093
IV	34	10	29.41	10.00	5.10	0 - 32.4	<0.001
V	101	9	8.91	12.70	3.20	1.98 - 25.7	0.092
VI	29	5	17.24	9.92	5.40	0 - 37.9	0.061
VII	9	4	44.44	9.28	9.60	0 - 55.6	<0.001
VIII	36	3	8.33	10.20	4.90	0 - 36.1	0.370
IX	4	0	0.00	9.12	14.00	0 - 100	0.464

Figure 2-figure supplement 2O. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species (excluding migratory birds). in this plate: Falconidae and Psittacidae.

Appendix 2.8.5. Supplementary data of Figure 2 (Fig. S3 from A to F) – Migratory species (fam > 10 spp)

BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	25.00	13.00	2.90	3.2 - 24	<0.001
2	27.10	27.00	4.20	12 - 44	0.815
3	18.80	30.00	4.70	14 - 48	0.001
4	9.38	20.00	3.80	8.3 - 36	0.001
5	9.38	8.30	2.50	1.1 - 19	0.577
6	9.38	2.20	1.40	0 - 8.7	<0.001
7	0.00	0.37	0.62	0 - 4.3	0.700
8	1.04	0.04	0.20	0 - 2.2	0.033
9	0.00	0.00	0.04	0 - 1.1	0.998
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Anatidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	32	2	6.25	3.96	3.40	0 - 21.9	0.143
II	42	5	11.90	4.32	3.10	0 - 19	0.007
II/III	31	1	3.23	3.93	3.50	0 - 22.6	0.525
III	12	0	0.00	3.43	5.20	0 - 33.3	0.523
IV	45	0	0.00	4.46	3.00	0 - 17.8	<0.001
V	47	0	0.00	4.53	2.90	0 - 17	<0.001
VI	65	4	6.15	5.50	2.70	0 - 16.9	0.398
VII	53	4	7.55	4.83	2.80	0 - 18.9	0.116
VIII	52	5	9.62	4.82	2.90	0 - 19.2	0.038
IX	41	16	39.02	4.30	3.10	0 - 24.4	<0.001

BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	31.20	13.00	7.20	0 - 44	0.003
2	18.80	26.00	10.00	0 - 62	0.201
3	18.80	29.00	12.00	0 - 81	0.147
4	18.80	20.00	9.30	0 - 57	0.913
5	0.00	8.90	6.50	0 - 40	0.196
6	0.00	2.50	3.80	0 - 21	0.657
7	12.50	0.45	1.70	0 - 15	0.001
8	0.00	0.04	0.51	0 - 7.7	0.994
9	0.00	0.00	0.07	0 - 6.7	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Caprimulgidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	3	0	0.00	3.40	10.00	0 - 66.7	0.110
II	9	3	33.33	5.87	7.40	0 - 44.4	0.001
II/III	7	0	0.00	4.69	7.70	0 - 42.9	0.419
III	5	0	0.00	3.74	8.30	0 - 60	0.214
IV	7	1	14.29	4.73	7.70	0 - 42.9	0.035
V	3	0	0.00	3.16	10.00	0 - 100	0.102
VI	5	1	20.00	3.87	8.50	0 - 60	0.011
VII	4	0	0.00	3.52	9.10	0 - 75	0.157
VIII	3	0	0.00	3.23	10.00	0 - 66.7	0.105
IX	0	0	0.00	0.00	0.00	0 - 0	1.000

BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	7.14	2.00	3.50	0 - 21	0.025
2	21.40	8.30	6.50	0 - 36	0.008
3	14.30	19.00	9.50	0 - 50	0.234
4	0.00	27.00	12.00	0 - 71	0.014
5	21.40	24.00	11.00	0 - 64	0.820
6	28.60	14.00	8.10	0 - 46	0.017
7	0.00	5.00	5.30	0 - 29	0.459
8	7.14	1.00	2.60	0 - 15	0.011
9	0.00	0.13	0.98	0 - 14	0.981
10	0.00	0.00	0.12	0 - 7.1	1.000

Biome	Apodidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	5	0	0.00	0.33	2.60	0 - 40	0.017
II	7	0	0.00	0.38	2.30	0 - 28.6	0.027
II/III	2	0	0.00	0.26	3.60	0 - 50	0.005
III	2	1	50.00	0.19	3.10	0 - 50	<0.001
IV	6	0	0.00	0.34	2.40	0 - 33.3	0.021
V	11	0	0.00	0.88	2.80	0 - 18.2	0.105
VI	8	0	0.00	0.46	2.40	0 - 25	0.038
VII	8	0	0.00	0.42	2.30	0 - 12.5	0.035
VIII	7	0	0.00	0.36	2.30	0 - 28.6	0.026
IX	4	0	0.00	0.23	2.40	0 - 25	0.009

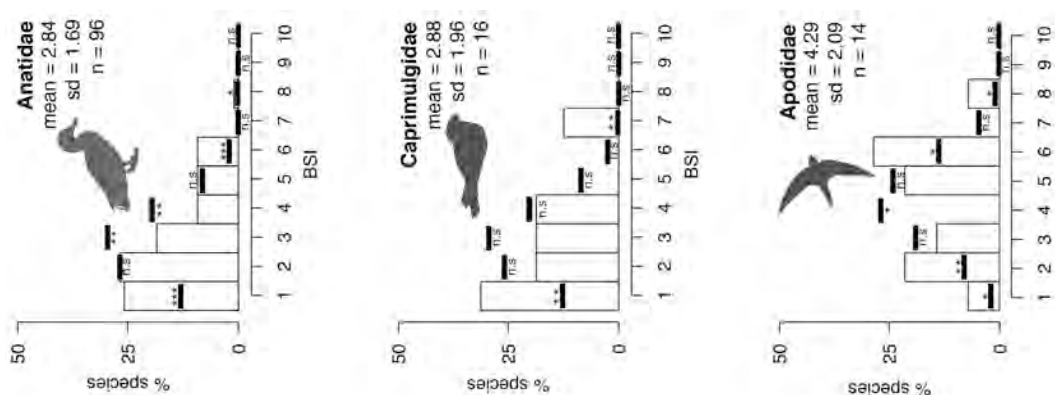
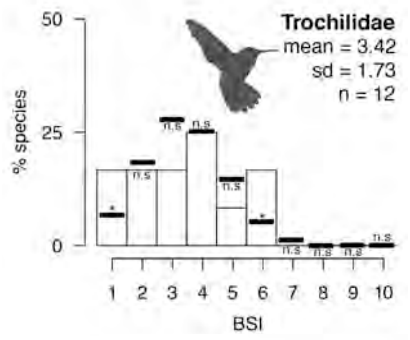
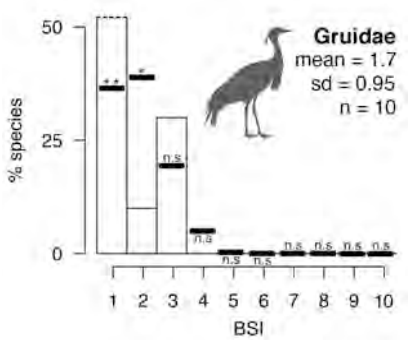


Figure 2-figure supplement 3A. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species considering only migratory species. in this plate: Anatidae, Caprimulgidae and Apodidae.



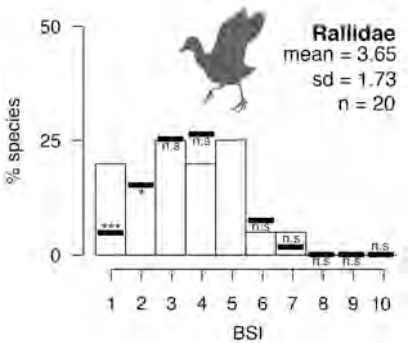
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	16.70	6.60	6.40	0 - 33	0.027
2	16.70	18.00	9.80	0 - 50	0.729
3	16.70	28.00	13.00	0 - 75	0.129
4	25.00	25.00	12.00	0 - 82	0.624
5	8.33	15.00	9.10	0 - 60	0.136
6	16.70	5.50	6.10	0 - 50	0.036
7	0.00	1.30	3.10	0 - 18	0.855
8	0.00	0.15	1.10	0 - 10	0.982
9	0.00	0.01	0.30	0 - 9.1	0.999
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Trochilidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	1	0	0.00	0.94	9.70	0 - 100	0.009
II	2	0	0.00	1.15	7.50	0 - 50	0.023
II/III	5	1	20.00	1.77	5.80	0 - 40	0.001
III	4	1	25.00	1.52	6.00	0 - 50	0.001
IV	6	0	0.00	1.93	5.50	0 - 33.3	0.128
V	4	0	0.00	1.62	6.30	0 - 50	0.068
VI	8	0	0.00	2.97	5.80	0 - 37.5	0.285
VII	6	0	0.00	1.96	5.60	0 - 33.3	0.129
VIII	4	0	0.00	1.56	6.20	0 - 75	0.066
IX	1	0	0.00	1.08	10.00	0 - 100	0.011



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	60.00	36.00	13.00	0 - 78	0.006
2	10.00	39.00	17.00	0 - 89	0.017
3	30.00	20.00	12.00	0 - 83	0.233
4	0.00	4.70	6.70	0 - 43	0.635
5	0.00	0.52	2.50	0 - 33	0.958
6	0.00	0.03	0.58	0 - 14	0.998
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

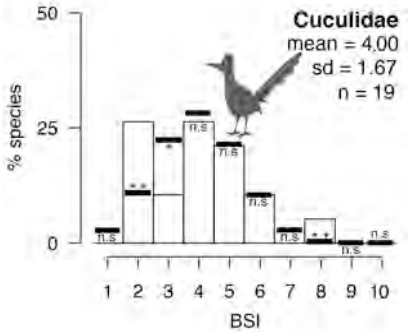
Biome	Gruidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	1	0	0.00	13.40	34.00	0 - 100	0.155
II/III	1	0	0.00	12.90	34.00	0 - 100	0.149
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	0	0	0.00	0.00	0.00	0 - 0	1.000
VI	4	1	25.00	19.20	18.00	0 - 75	0.173
VII	5	3	60.00	23.40	17.00	0 - 80	0.003
VIII	4	1	25.00	19.40	18.00	0 - 100	0.181
IX	2	1	50.00	14.70	25.00	0 - 100	0.018



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	20.00	5.20	4.50	0 - 25	0.001
2	0.00	15.00	7.10	0 - 42	0.025
3	25.00	26.00	9.40	0 - 63	0.762
4	20.00	27.00	9.90	0 - 63	0.226
5	25.00	18.00	7.70	0 - 71	0.140
6	5.00	7.50	5.40	0 - 32	0.217
7	5.00	1.90	2.90	0 - 20	0.099
8	0.00	0.29	1.20	0 - 11	0.944
9	0.00	0.02	0.30	0 - 5.3	0.997
10	0.00	0.00	0.07	0 - 5	1.000

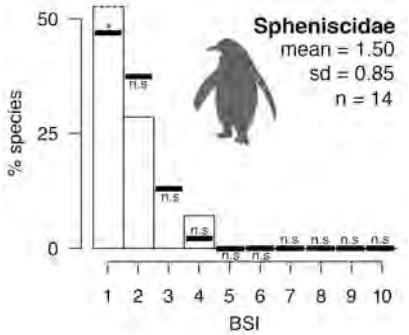
Biome	Rallidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	7	0	0.00	1.11	3.90	0 - 42.9	0.083
II	11	1	9.09	1.57	3.70	0 - 36.4	0.012
II/III	7	0	0.00	1.11	4.00	0 - 42.9	0.082
III	2	0	0.00	0.82	6.30	0 - 50	0.017
IV	9	0	0.00	1.34	3.70	0 - 22.2	0.133
V	7	0	0.00	1.17	4.00	0 - 42.9	0.087
VI	13	2	15.38	2.11	3.80	0 - 23.1	0.001
VII	9	0	0.00	1.31	3.80	0 - 33.3	0.128
VIII	7	1	14.29	1.14	4.00	0 - 28.6	0.001
IX	1	0	0.00	0.85	9.20	0 - 100	0.009

Figure 2-figure supplement 3B. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species considering only migratory species. in this plate: Trochilidae, Gruidae and Rallidae.



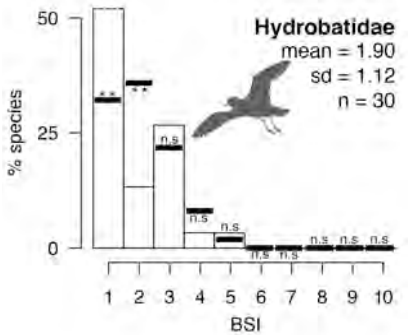
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	0.00	2.90	3.60	0 - 21	0.555
2	26.30	11.00	6.10	0 - 37	0.003
3	10.50	23.00	8.90	0 - 58	0.042
4	26.30	28.00	10.00	0 - 68	0.835
5	21.10	22.00	8.90	0 - 58	0.684
6	10.50	11.00	6.20	0 - 37	0.518
7	0.00	3.00	3.70	0 - 22	0.536
8	5.26	0.47	1.50	0 - 11	0.007
9	0.00	0.02	0.36	0 - 5.6	0.995
10	0.00	0.00	0.09	0 - 5.3	1.000

Biome	Cucuidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	10	0	0.00	0.67	2.60	0 - 30	0.070
II	14	0	0.00	1.16	2.80	0 - 14.3	0.184
II/III	7	0	0.00	0.46	2.50	0 - 28.6	0.033
III	1	0	0.00	0.30	5.50	0 - 100	0.003
IV	5	0	0.00	0.41	2.80	0 - 20	0.021
V	12	0	0.00	0.84	2.60	0 - 16.7	0.109
VI	11	0	0.00	0.72	2.50	0 - 18.2	0.085
VII	7	0	0.00	0.51	2.70	0 - 28.6	0.037
VIII	7	0	0.00	0.48	2.60	0 - 28.6	0.035
IX	2	0	0.00	0.32	4.00	0 - 50	0.006



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	64.30	47.00	10.00	9.1 - 79	0.022
2	28.60	37.00	14.00	0 - 91	0.342
3	0.00	13.00	8.30	0 - 45	0.126
4	7.14	2.40	4.10	0 - 30	0.344
5	0.00	0.24	1.40	0 - 10	0.972
6	0.00	0.01	0.32	0 - 10	0.999
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

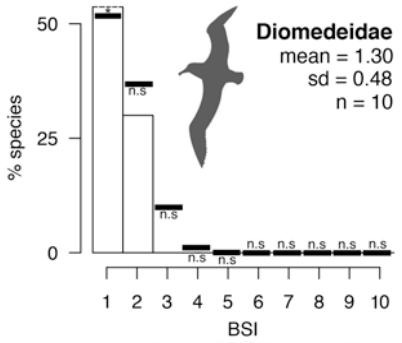
Biome	Spheniscidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	0	0	0.00	0.00	0.00	0 - 0	1.000
II/III	0	0	0.00	0.00	0.00	0 - 0	1.000
III	2	0	0.00	13.90	24.00	0 - 100	0.356
IV	2	0	0.00	14.10	24.00	0 - 100	0.363
V	2	0	0.00	13.90	24.00	0 - 100	0.356
VI	2	0	0.00	13.90	24.00	0 - 100	0.358
VII	3	1	33.33	15.30	20.00	0 - 100	0.052
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	10	8	80.00	42.60	11.00	0 - 80	<0.001



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	53.30	32.00	7.10	7.7 - 60	0.001
2	13.30	36.00	9.30	4 - 69	0.004
3	26.70	22.00	7.50	0 - 54	0.342
4	3.33	8.20	4.80	0 - 39	0.083
5	3.33	2.00	2.60	0 - 16	0.769
6	0.00	0.30	1.00	0 - 8.3	0.924
7	0.00	0.04	0.37	0 - 4.3	0.991
8	0.00	0.00	0.09	0 - 4	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

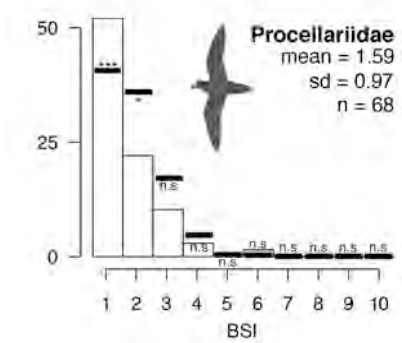
Biome	Hydrobatidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	4	1	25.00	12.60	16.00	0 - 100	0.085
II	3	0	0.00	12.10	19.00	0 - 100	0.476
II/III	2	0	0.00	11.40	22.00	0 - 100	0.279
III	6	3	50.00	13.60	14.00	0 - 83.3	0.003
IV	5	0	0.00	12.80	15.00	0 - 80	<0.001
V	7	1	14.29	14.00	13.00	0 - 71.4	0.336
VI	11	2	18.18	17.00	10.00	0 - 72.7	0.381
VII	3	1	33.33	12.10	19.00	0 - 100	0.041
VIII	3	0	0.00	12.10	19.00	0 - 100	0.477
IX	13	8	61.54	19.10	9.80	0 - 53.8	<0.001

Figure 2-figure supplement 3C. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species considering only migratory species. in this plate: Cuculidae, Spheniscidae and Hydrobatidae.



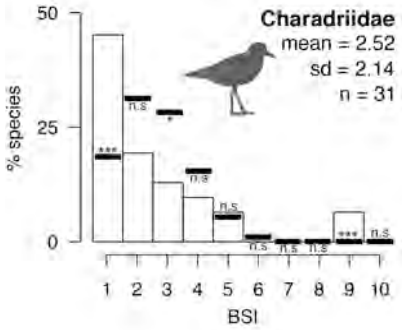
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	70.00	52.00	14.00	0 - 90	0.037
2	30.00	37.00	16.00	0 - 86	0.570
3	0.00	10.00	9.70	0 - 50	0.372
4	0.00	1.20	3.80	0 - 33	0.913
5	0.00	0.05	0.80	0 - 17	0.997
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Diomedeidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	1	0	0.00	20.70	41.00	0 - 100	0.261
II/III	0	0	0.00	0.00	0.00	0 - 0	1.000
III	1	0	0.00	20.00	40.00	0 - 100	0.250
IV	0	0	0.00	0.00	0.00	0 - 0	1.000
V	3	3	100.00	25.40	24.00	0 - 100	<0.001
VI	0	0	0.00	0.00	0.00	0 - 0	1.000
VII	2	0	0.00	22.70	29.00	0 - 100	0.708
VIII	0	0	0.00	0.00	0.00	0 - 0	1.000
IX	6	4	66.67	45.20	16.00	0 - 100	0.026



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	63.20	41.00	5.10	22 - 59	<0.001
2	22.10	36.00	6.40	14 - 63	0.012
3	10.30	17.00	4.50	3.2 - 35	0.061
4	2.94	4.90	2.60	0 - 18	0.241
5	0.00	0.86	1.20	0 - 7.7	0.602
6	1.47	0.09	0.40	0 - 3.9	0.054
7	0.00	0.00	0.09	0 - 1.9	0.997
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.02	0 - 1.9	1.000
10	0.00	0.00	0.00	0 - 0	1.000

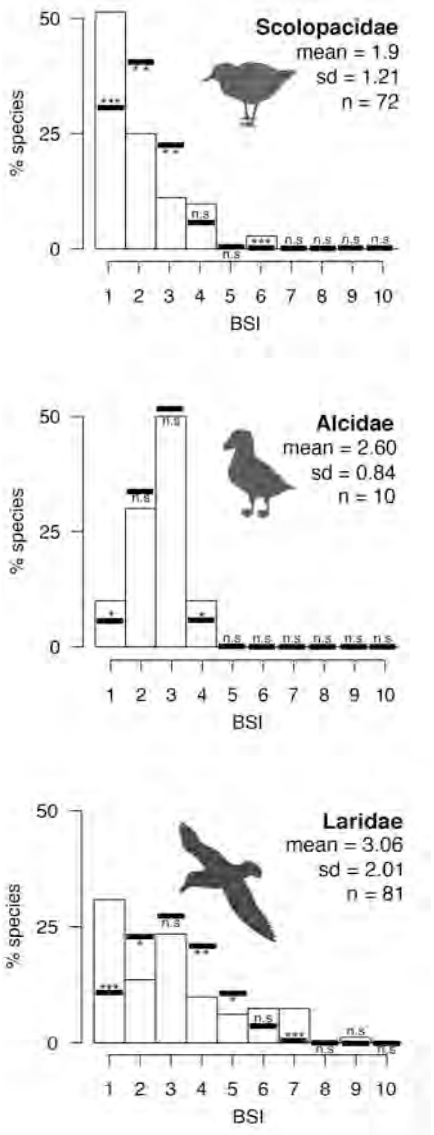
Biome	Procellariidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	12	7	58.33	19.30	11.00	0 - 66.7	<0.001
II	4	2	50.00	16.70	18.00	0 - 100	0.013
II/III	3	2	66.67	16.40	21.00	0 - 100	0.004
III	3	2	66.67	16.40	21.00	0 - 100	0.005
IV	10	3	30.00	18.90	12.00	0 - 70	0.106
V	27	11	40.74	26.40	7.60	0 - 55.6	0.018
VI	14	1	7.14	20.20	10.00	0 - 64.3	0.034
VII	9	2	22.22	18.20	13.00	0 - 66.7	0.266
VIII	3	0	0.00	16.50	21.00	0 - 100	0.727
IX	23	13	56.52	24.10	8.10	0 - 56.5	<0.001



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	45.20	18.00	5.70	0 - 37	<0.001
2	19.40	31.00	8.00	3.4 - 61	0.061
3	12.90	29.00	8.10	3.2 - 61	0.015
4	9.68	15.00	5.90	0 - 38	0.125
5	6.45	5.30	3.70	0 - 23	0.739
6	0.00	1.20	1.90	0 - 13	0.691
7	0.00	0.16	0.73	0 - 6.9	0.953
8	0.00	0.02	0.23	0 - 6.5	0.996
9	6.45	0.00	0.09	0 - 3.6	<0.001
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Charadriidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	3	0	0.00	4.61	12.00	0 - 100	0.152
II	5	2	40.00	4.94	9.60	0 - 60	0.001
II/III	2	0	0.00	4.54	15.00	0 - 100	0.097
III	4	0	0.00	4.64	10.00	0 - 75	0.211
IV	6	0	0.00	5.20	8.90	0 - 50	0.387
V	7	0	0.00	5.35	8.20	0 - 42.9	0.487
VI	16	2	12.50	8.51	6.40	0 - 37.5	0.153
VII	18	7	38.89	9.76	6.40	0 - 38.9	<0.001
VIII	7	0	0.00	5.32	8.30	0 - 57.1	0.477
IX	10	3	30.00	5.96	7.20	0 - 50	0.001

Figure 2-figure supplement 3D. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species considering only migratory species. in this plate: Diomedeidae, Procellariidae and Charadriidae.



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	51.40	30.00	4.30	13 - 48	<0.001
2	25.00	40.00	6.00	12 - 63	0.004
3	11.10	23.00	4.50	6.1 - 41	0.003
4	9.72	5.70	2.50	0 - 17	0.061
5	0.00	0.63	0.94	0 - 6.2	0.649
6	2.78	0.03	0.23	0 - 1.6	<0.001
7	0.00	0.00	0.03	0 - 1.6	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Scolopacidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	1	0	0.00	7.27	26.00	0 - 100	0.078
II	2	0	0.00	7.61	19.00	0 - 100	0.172
II/III	2	0	0.00	8.07	19.00	0 - 100	0.183
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	3	0	0.00	7.79	16.00	0 - 100	0.273
V	4	0	0.00	8.02	13.00	0 - 75	0.405
VI	24	0	0.00	11.20	6.00	0 - 37.5	<0.001
VII	17	0	0.00	9.72	6.80	0 - 41.2	<0.001
VIII	42	12	28.57	17.90	4.90	2.38 - 38.1	0.009
IX	42	25	59.52	17.90	4.90	2.38 - 35.7	<0.001

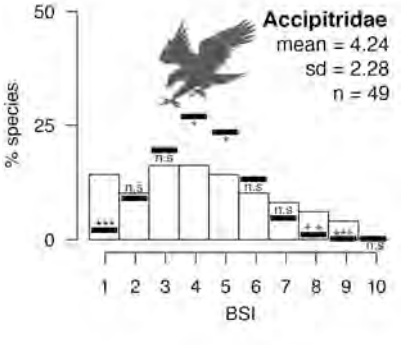
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	10.00	5.50	5.80	0 - 20	0.049
2	30.00	34.00	12.00	0 - 50	0.884
3	50.00	55.00	11.00	40 - 89	0.977
4	10.00	5.70	5.00	0 - 11	0.023
5	0.00	0.00	0.00	0 - 0	1.000
6	0.00	0.00	0.00	0 - 0	1.000
7	0.00	0.00	0.00	0 - 0	1.000
8	0.00	0.00	0.00	0 - 0	1.000
9	0.00	0.00	0.00	0 - 0	1.000
10	0.00	0.00	0.00	0 - 0	1.000

Biome	Alcidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	0	0	0.00	0.00	0.00	0 - 0	1.000
II	0	0	0.00	0.00	0.00	0 - 0	1.000
II/III	0	0	0.00	0.00	0.00	0 - 0	1.000
III	0	0	0.00	0.00	0.00	0 - 0	1.000
IV	1	0	0.00	0.29	5.40	0 - 100	0.003
V	0	0	0.00	0.00	0.00	0 - 0	1.000
VI	7	0	0.00	0.89	3.50	0 - 14.3	0.067
VII	0	0	0.00	0.00	0.00	0 - 0	1.000
VIII	9	0	0.00	2.66	4.70	0 - 11.1	0.314
IX	9	1	11.11	2.72	4.80	0 - 11.1	<0.001

BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	30.90	12.00	3.10	2.5 - 23	<0.001
2	13.60	23.00	4.30	8.8 - 40	0.010
3	23.50	28.00	5.10	12 - 45	0.247
4	9.88	21.00	4.40	6.2 - 38	0.003
5	6.17	11.00	3.20	0 - 24	0.041
6	7.41	4.00	2.00	0 - 14	0.079
7	7.41	0.97	1.10	0 - 7.6	<0.001
8	0.00	0.16	0.45	0 - 3.8	0.883
9	1.23	0.02	0.14	0 - 1.4	0.012
10	0.00	0.00	0.02	0 - 1.2	1.000

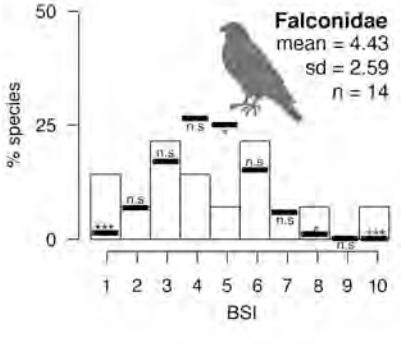
Biome	Laridae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	23	1	4.35	3.49	3.70	0 - 21.7	0.240
II	27	1	3.70	3.70	3.60	0 - 22.2	0.356
II/III	18	0	0.00	3.10	4.00	0 - 22.2	0.784
III	22	5	22.73	3.37	3.80	0 - 22.7	<0.001
IV	24	1	4.17	3.45	3.60	0 - 20.8	0.240
V	28	1	3.57	3.81	3.50	0 - 21.4	0.418
VI	37	1	2.70	4.50	3.30	0 - 18.9	0.210
VII	30	6	20.00	3.95	3.50	0 - 20	<0.001
VIII	20	1	5.00	3.32	4.00	0 - 25	0.167
IX	19	8	42.11	3.16	4.00	0 - 26.3	<0.001

Figure 2-figure supplement 3E. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species considering only migratory species. in this plate: Scolopacidae, Alcidae and Laridae.



BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	14.30	2.10	1.90	0 - 10	<0.001
2	10.20	8.70	3.60	0 - 22	0.326
3	16.30	20.00	5.20	2 - 43	0.259
4	16.30	27.00	6.30	4.1 - 53	0.027
5	14.30	23.00	5.70	4.1 - 49	0.035
6	10.20	13.00	4.30	0 - 31	0.217
7	8.16	4.80	2.70	0 - 16	0.080
8	6.12	1.00	1.40	0 - 8.3	0.003
9	4.08	0.11	0.48	0 - 4.2	<0.001
10	0.00	0.01	0.11	0 - 2.1	0.997

Biome	Accipitridae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	8	0	0.00	0.22	1.70	0 - 12.5	0.018
II	14	0	0.00	0.30	1.50	0 - 14.3	0.043
II/III	19	1	5.26	0.33	1.30	0 - 10.5	0.002
III	17	0	0.00	0.31	1.30	0 - 11.8	0.054
IV	25	0	0.00	0.44	1.30	0 - 8	0.118
V	22	0	0.00	0.39	1.30	0 - 13.6	0.092
VI	34	0	0.00	0.71	1.40	0 - 11.8	0.281
VII	36	4	11.11	0.83	1.50	0 - 11.1	<0.001
VIII	25	1	4.00	0.44	1.30	0 - 12	0.004
IX	8	1	12.50	0.23	1.70	0 - 12.5	<0.001

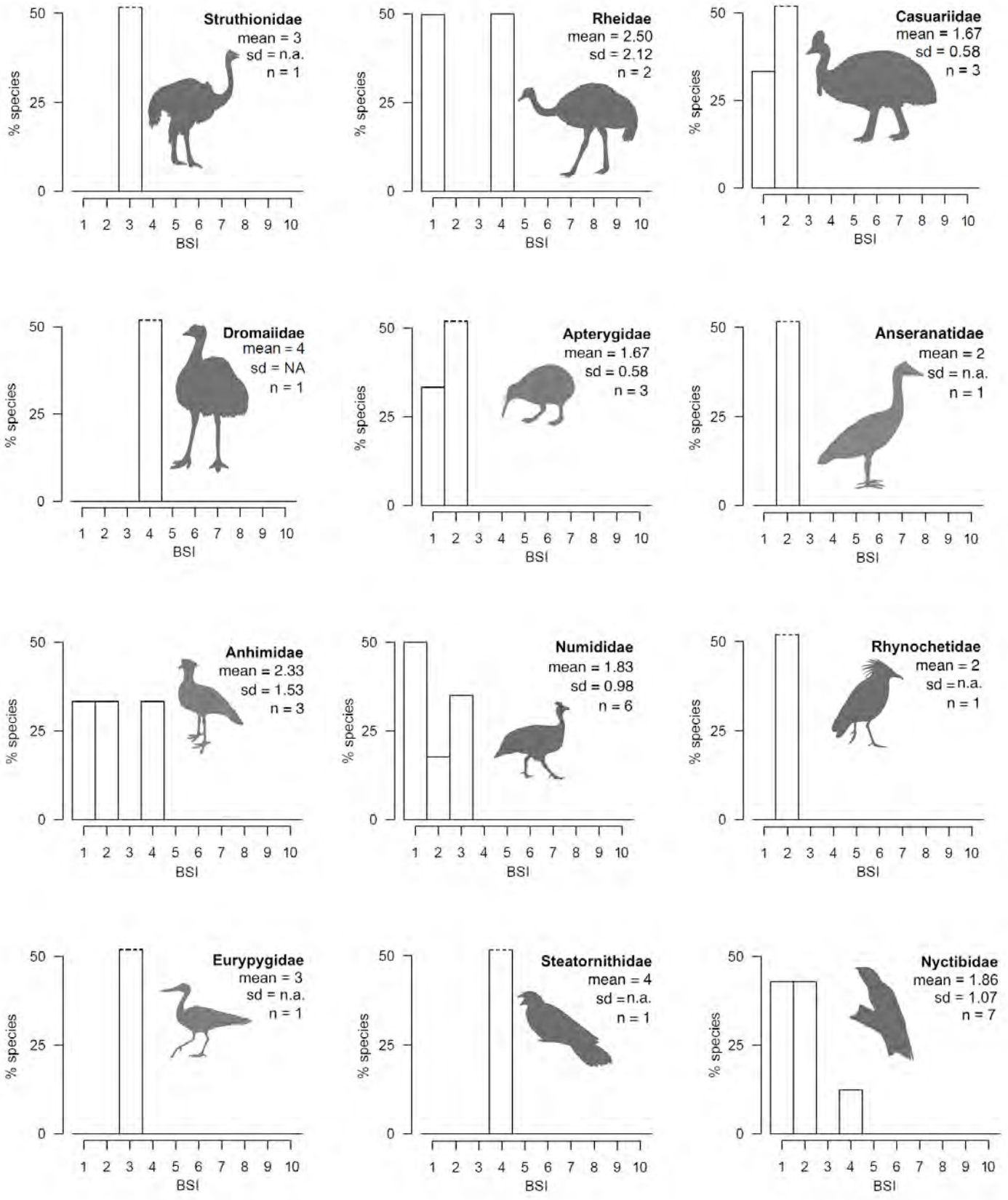


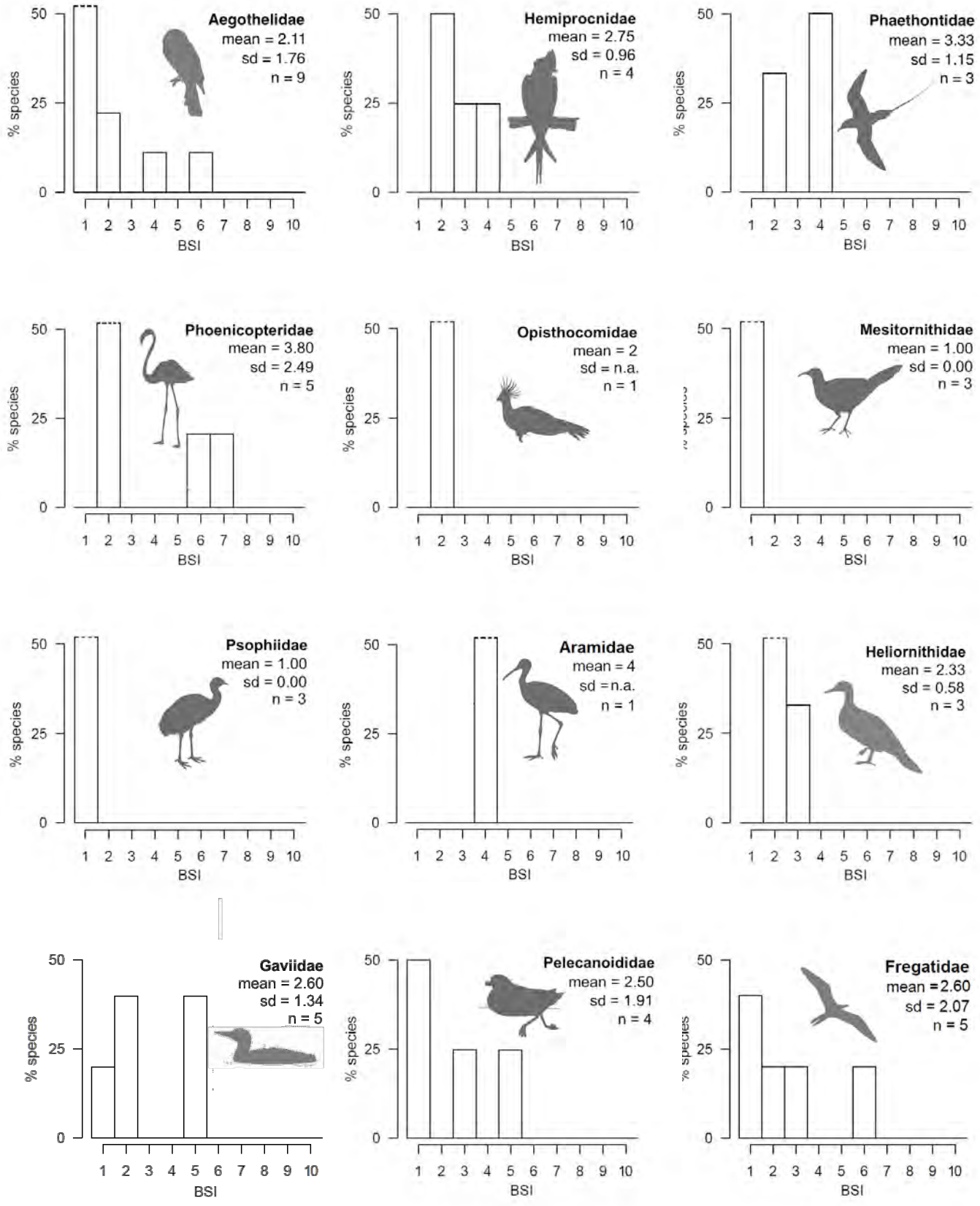
BSI	%	Monte Carlo Analysis			
		Mean %	S.d.	Range	*p*
1	14.30	1.60	3.20	0 - 21	<0.001
2	7.14	7.00	6.10	0 - 29	0.348
3	21.40	17.00	8.90	0 - 50	0.241
4	14.30	26.00	12.00	0 - 71	0.090
5	7.14	25.00	11.00	0 - 71	0.017
6	21.40	15.00	8.50	0 - 46	0.155
7	0.00	5.90	5.70	0 - 29	0.390
8	7.14	1.30	3.00	0 - 21	0.015
9	0.00	0.14	1.00	0 - 14	0.981
10	7.14	0.01	0.23	0 - 7.7	<0.001

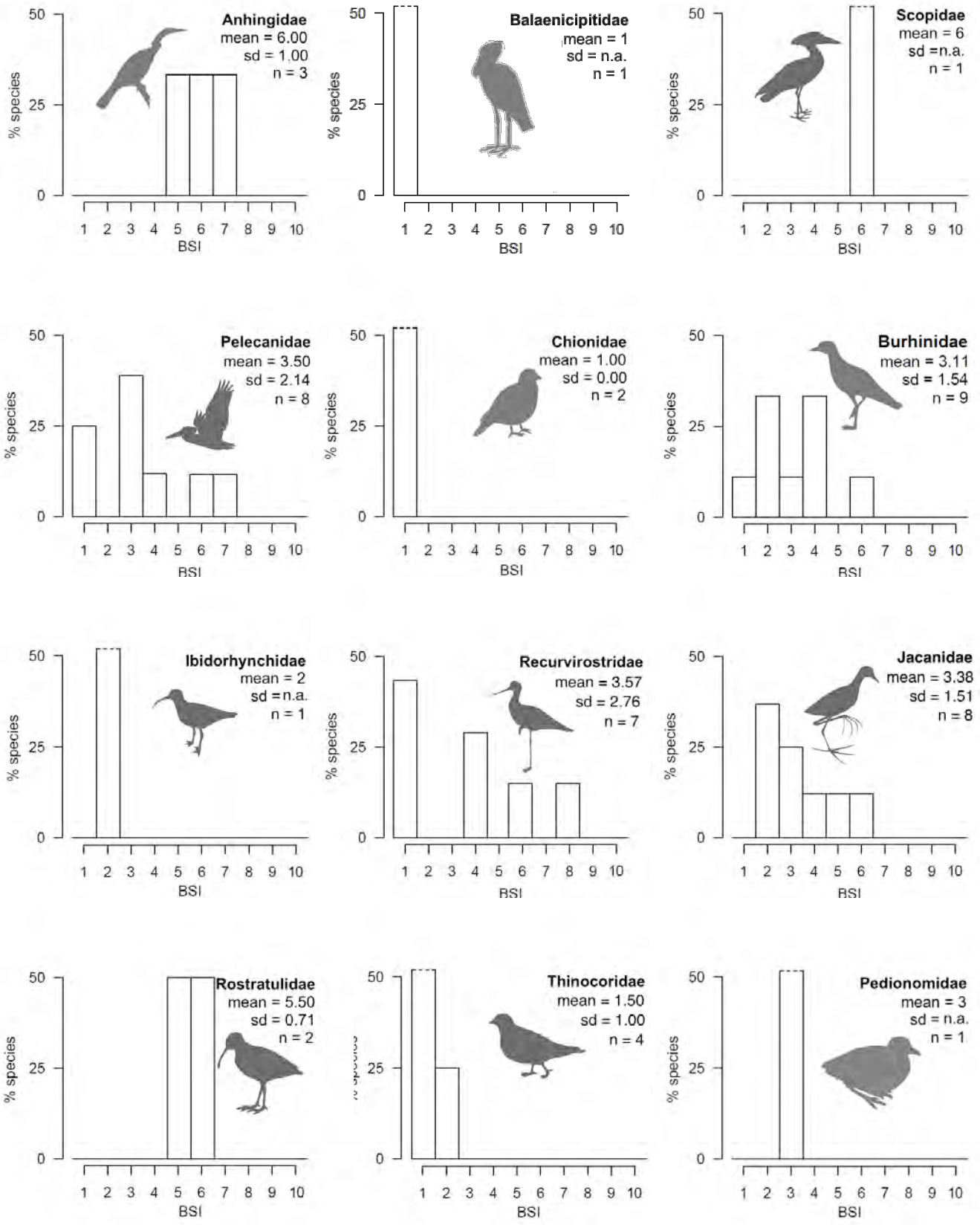
Biome	Falconidae			Monte Carlo Analysis			
	sp	sp (BSI=1)	%	Mean %	S.d.	Range	*p*
I	1	0	0.00	0.12	3.50	0 - 100	0.001
II	5	0	0.00	0.23	2.20	0 - 20	0.012
II/III	5	0	0.00	0.24	2.20	0 - 20	0.012
III	7	1	14.29	0.27	1.90	0 - 14.3	<0.001
IV	9	1	11.11	0.44	2.20	0 - 22.2	<0.001
V	5	0	0.00	0.23	2.10	0 - 20	0.012
VI	10	0	0.00	0.55	2.30	0 - 20	0.058
VII	9	0	0.00	0.46	2.20	0 - 22.2	0.043
VIII	8	0	0.00	0.33	2.00	0 - 25	0.027
IX	3	0	0.00	0.14	2.20	0 - 33.3	0.004

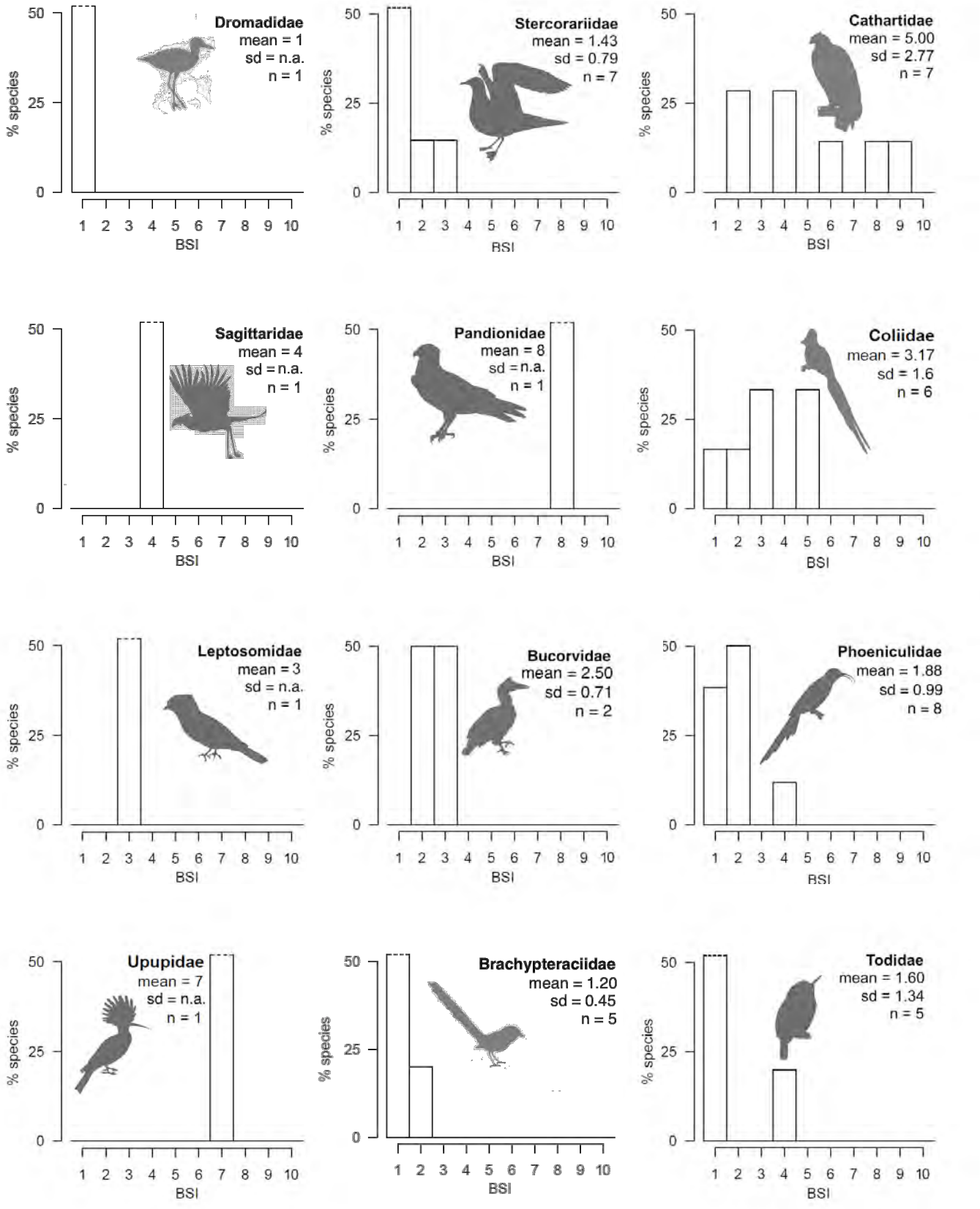
Figure 2-figure supplement 3F. Data and Results for the Monte Carlo Analysis in the Non-Passerine Families with more than 10 species considering only migratory species. in this plate: Accipitridae and Falconidae.

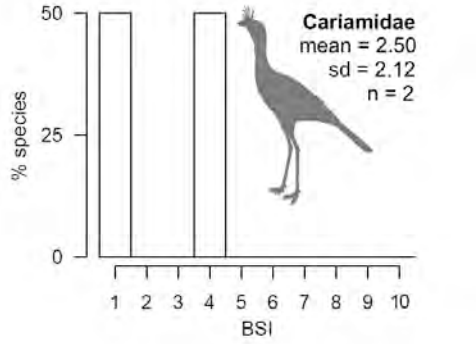
Appendix 2.8.6. Supplementary data of Figure 2 (Figures S4) – Species of families (< 10 spp)



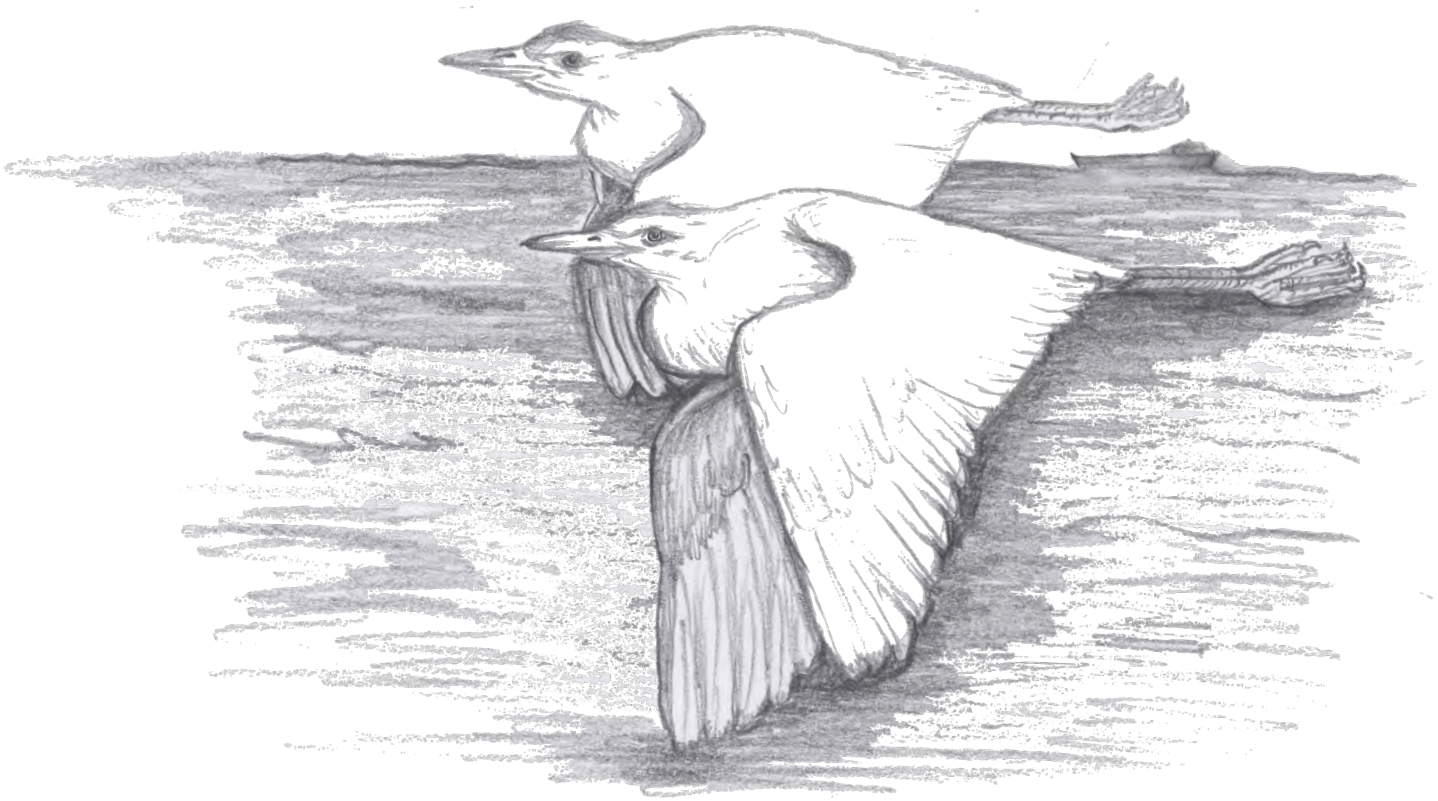

Aegothelidae
mean = 2.11
sd = 1.76
n = 9
Hemiprocnidae
mean = 2.75
sd = 0.96
n = 4
Phaethontidae
mean = 3.33
sd = 1.15
n = 3
Phoenicopteridae
mean = 3.80
sd = 2.49
n = 5
Opisthocomidae
mean = 2
sd = n.a.
n = 1
Mesitornithidae
mean = 1.00
sd = 0.00
n = 3
Psophiidae
mean = 1.00
sd = 0.00
n = 3
Aramidae
mean = 4
sd = n.a.
n = 1
Heliornithidae
mean = 2.33
sd = 0.58
n = 3
Gaviidae
mean = 2.60
sd = 1.34
n = 5
Pelecanoididae
mean = 2.50
sd = 1.91
n = 4
Fregatidae
mean = 2.60
sd = 2.07
n = 5
% species
BSI


Anhingidae
mean = 6.00
sd = 1.00
n = 3
Balaenicipitidae
mean = 1
sd = n.a.
n = 1
Scopidae
mean = 6
sd =n.a.
n = 1
Pelecanidae
mean = 3.50
sd = 2.14
n = 8
Chionidae
mean = 1.00
sd = 0.00
n = 2
Burhinidae
mean = 3.11
sd = 1.54
n = 9
Ibidorhynchidae
mean = 2
sd =n.a.
n = 1
Recurvirostridae
mean = 3.57
sd = 2.76
n = 7
Jacanidae
mean = 3.38
sd = 1.51
n = 8
Rostratulidae
mean = 5.50
sd = 0.71
n = 2
Thinocoridae
mean = 1.50
sd = 1.00
n = 4
Pedionomidae
mean = 3
sd = n.a.
n = 1
% species
BSI


Dromadidae
mean = 1
sd = n.a.
n = 1
Stercorariidae
mean = 1.43
sd = 0.79
n = 7
Cathartidae
mean = 5.00
sd = 2.77
n = 7
Sagittaridae
mean = 4
sd = n.a.
n = 1
Pandionidae
mean = 8
sd = n.a.
n = 1
Coliidae
mean = 3.17
sd = 1.6
n = 6
Leptosomidae
mean = 3
sd = n.a.
n = 1
Bucorvidae
mean = 2.50
sd = 0.71
n = 2
Phoeniculidae
mean = 1.88
sd = 0.99
n = 8
Upupidae
mean = 7
sd = n.a.
n = 1
Brachypteraciidae
mean = 1.20
sd = 0.45
n = 5
Todidae
mean = 1.60
sd = 1.34
n = 5
% species
BSI
0
25
50
1 2 3 4 5 6 7 8 9 10


Cariamidae
mean = 2.50
sd = 2.12
n = 2
% species
50
25
0
1 2 3 4 5 6 7 8 9 10
BSI

3 Paleobiogeographic history



3 Out of South America: adding fossils and tectonics for a new biogeographic history of modern birds (Neornithes)

"…The animal kingdom developed in Australia shows anomalies and peculiarities perhaps even more extraordinary than the displayed by plants. Nevertheless, since the dispersion capacity of the various groups of animals varies greatly, there is less uniformity in the phenomena they present."

Alfred Russel Wallace (1893)

"The extreme rarity of transitional forms in the fossil record persists as the trade secret of paleontology. The evolutionary trees that adorn our textbooks have data only at the tips and nodes of the branches; the rest is inference, however reasonable, not the evidence of fossils."

Stephen Jay Gould *(1941-2002)*

ABSTRACT

Birds are one of the most specious groups of terrestrial vertebrates and inhabit all the ecosystems of the Earth. This adaptive success is related without doubt to the development of a prominent fly capacity. This trait allowed that early birds reached an important dispersal capacity and colonized diverse novel environments. With the aim of reconstructing the most probable biogeographic scenario of the origin and early diversification of birds, we considered diverse roles of dispersal capacity to explain the

large-scale geographic patterns showed by Neornithes lineages. Bird evolution in a geographic context was reconstructed based on their phylogenetic relationships, taking into account paleontological information for the calibration of divergence processes. We also considered ancestral taxa as well as tectonic and paleoclimatic information. According with our results, we propose a Neornithes origin in South America. The most probable evolutionary model implied the role of South America as refugia during the late Cretaceous environmental changes, which allowed the survival of early neornithine birds. Moreover, we propose three main dispersal waves. The first one, during the late Cretaceous protagonized by Palaeognathae, Galloanseres and Aequornithes. Second, there was a great diversification during the Paleocene-Eocene in terrestrial-dwelling lineages (Caprimulgimorphae and Telluraves), which was related with global warming conditions expanding tropical environments. Third, the expansion of niches diversity due to appearance of new marine currents generated by cooling trends along the Oligocene and grassland biomes across the late Oligocene and Early Miocene triggered a new dispersal wave of marine and terrestrial lineages respectively (Charadriiformes, Procellariformes, Galliformes, Otidiformes, etc). Overall, our results suggest a preponderant role of global climate and tectonics in dispersal and vicariance events configuring the modern distribution and diversity of bird families. In spite of the incompleteness of the avian fossil record, this approach indicates the importance of integrate all the available information to postulate a holistic model for bird evolution within a deep-time scale.

Key words. Birds, dispersal-extinction-cladogenesis (DEC) analysis, historical biogeography, paleobiogegraphy, Lagrange.

3.2. INTRODUCTION

Birds (Aves), with near 10,000 living species, are one of the most specious clade of terrestrial vertebrates (Gill 2007; Jetz et al. 2012; Del Hoyo and Collar 2014). They are spread across all continents and a wide array of environments, being the result of an extraordinary radiation that spans since the late Jurassic —when they evolved from derived Theropods— to the striking variety of ecological and morphological adaptations that they currently hold (Chiappe and Witmer 2002; Zhou 2004). Our

knowledge of their current biology, ecology and distribution is vast, and growing paleontological evidence is clarifying key morphological steps of their evolutionary history (Mayr 2009, 2014b; Ksepka and Boyd 2012). However, we require an understanding of the deep-time context of such radiation to clarify the possible relationship between historical events and their current geographic distributions.

The evolutionary relationships of modern birds (Neornithes) at higher level (orders and families) are now relatively well established due to molecular and morphological studies (Dyke and van Tuinen 2004; Ericson et al. 2006; Livezey and Zusi 2007; Hackett et al. 2008; Pacheco et al. 2011; Jetz et al. 2012; Lee et al. 2014; Jarvis et al. 2014). Some of these phylogenetic approaches were dated with paleontological information suggesting that stem groups of modern lineages arose during the Upper Cretaceous and diversified around or soon after K/T limit. Furthermore, some authors argue that basal emergence of Neornithes happened in Gondwana before the Cretaceous-Palaeogene boundary (Cooper and Penny 1997; Cracraft 2001; Hope 2002; Longrich et al. 2011; Ericson 2012; Mayr 2014b). The evidence seems indicate that vicariance events during the Gondwana break up leaded the initial patterns of diversification in southern continents with subsequent dispersal events to the northern hemisphere (Cracraft 2001; Ericson et al. 2002; Ericson 2012). The mapping of phylogenetic relationships in groups such as Ratites (van Tuinen et al. 1998; Baker et al. 2014), Galloanserae (Crowe et al. 2006; Frank-Hoeflich et al. 2007), and Telluraves (Australavis and Afroaves) (Ericson 2012) are consistent with this model. All these clades present an evolutionary pattern explained by Gondwana drifting process during the Late Cretaceous (Cracraft 2001; Barker et al. 2004; Ericson 2012; Baker et al. 2014). Nevertheless, some conclusions generates debate because just a few clades are present in the late Cretaceous fossil record, and the oldest fossils of basal groups such as Paleognathae have only Tertiary record (Mayr 2009). The only bird groups with unambiguously fossils in the Cretaceous are Galloanseres and Aequornithes (Feduccia 2003; Clarke et al. 2005b; Ksepka and Boyd 2012; Ksepka et al. 2014; Mayr 2014b).

The continental drift theory was an important conceptual basis to understand the Earth dynamics (Wegener 1912). This theory explained many geographic patterns observed for diverse taxa worldwide and has provided an important support for evolutionary mechanisms such as vicariance and dispersion in biogeographic analyses

(Cracraft 1973; Ronquist 1997; Zink et al. 2000; McDowall 2004; Limolino et al. 2010; Contreras-Medina and Luna-Vega 2012). The historical variation of connections between landmasses and the climatic changes influencing sea levels were processes that promoted vicariance or dispersion scenarios due tothe appearance/disappearance of geographic and ecological barriers (Cracraft 1985; Cox 2000; Voelker 2002; Ree and Smith 2008; Springer et al. 2011; Hawkins et al. 2012; Condamine et al. 2013). Considering this, it is reasonable to think that distribution patterns and bird lineages diversity has been influenced by historical geologic processes. Some approaches in birds biogeographic reconstructions are usually limited in taxonomic scope (encompassing families or subfamilies), use ecological rather than geographic areas (for example, biogeographic zones realms instead of continents, which implicitly assumes that those areas existed throughout the entire time interval of analysis), do not include fossil information, or exclude the changing geographic configurations of landmasses through time in the analyses (Ericson 2012).

In this research we integrated an extensive data source from molecular phylogenies and paleontological studies with geological and climatic information within a historical context. This allowed us to develop an integrative macroevolutionary model that explains bird evolutionary patterns in relation with geographical origin of avian lineages and the influence of historical processes in bird evolution.

3.3. MATERIALS AND METHODS

3.3.1. Phylogenetic hypothesis

Paleobiogeographical reconstruction requires a robust, highly resolved, and time-calibrated tree (Ree and Smith 2008). Considering this, our study constructed a phylogenetic hypothesis based on Jarvis et al. (2014) for high-level clades and Jetz et al. (2012) at the family level. We also used additional information from the phylogenetic hypotheses based on molecular data of nuclear DNA analysis formulated by Ericson et al. (2006) and Hackett et al. (2008). Subsequently, we included the information of fossil birds with relatively well-established evolutionary relationship with respect to modern taxa (Mayr 2009, 2014b; Ksepka and Boyd 2012) (Table S1). We built a consensus tree that contains 215 bird clades (Fig. S1-S4 in Appendix 3.8): 100 non-passerine taxa and the Basal-Passeriformes clade, 43 extinct taxa that presented

phylogenetic information respect to recent families, and 70 fossil taxa used as *stem-clades* and points of calibration for divergences between clades (Table S2). The consensus tree was dated with the package Paleotree in R (R Development Core Team 2013). The fossil presence of ancient taxa also allowed the inclusion of ancestral occupation (AO) information in the analyses for clades that today present a different distribution with respect to the past. For example, the Hummingbirds (Trochilidae) inhabit nowadays New World environments, but fossil evidence indicates that they were present in Europe during the Paleogene (Mayr 2005a; Mayr and Micklich 2010).

3.3.2. Historical biogeographic analysis

Several considerations were taken into account to define our biogeographic analysis. First, the planet was divided into ten geologic units based on the tectonic history (Scotese et al. 1999; Scotese 2001): South America, North America (including Greenland, Central America and West Indies), Africa (including Arabia), Europe (considering from western Europe to the ancient Turgai sea way and the recent Urals mountains limits), Asia (from Ural mountains to Japan and from Siberia to Indochina and Sunda islands), India (Indian subcontinent and Tibetan plateau), Antarctica, Australasia (Australia, New Guinea, and Melanesian islands), Zealand (New Zealand and neighbour islands) and Malagasy region (Madagascar island and surrounding archipelagos) (Fig.S5). The distribution data of recent clades was registered as presence/absence in each area considering as criteria that the species of family occupied more than 30% of area. For lineages with marine distribution we considered the same criteria applied to their breeding area in the coast. In the case of the extinct lineages and the *stem*-groups, their ancestral occupation (AO) was coded with geographical data from the fossil record, according with their early apparition (Table S1 and S2). Marginal distributions (<30%), or expansion due to human activities were excluded due to these occupancy records are relatively recent and represent colonizations of punctual species that may affect the inference of origin areas at basal family level (Ree and Smith 2008; Condamine et al. 2013).

3.3.3. Paleobiogeographic analysis

For the reconstruction of the geographic origin and dispersal routes of bird lineages during their diversification throught time we employed the Dispersal-Extinction-Cladogenesis model (DEC) developed by Ree & Smith (2008). This method describes

transitions (ancestor-descendant) between geographical areas by interaction of three evolutionary processes: dispersion, local extinction (range contraction) and cladogenesis (vicariance). DEC method calculates the likelihood of each clade range as function of dispersal and extinction rates and estimates global rates of dispersal and extinction given all possible ancestral states at internal nodes. The analysis assumes those rates as constant to calculate the relative probability for geographic ancestral ranges in each one of the nodes along the phylogenetic hypothesis (Ree and Smith 2008; Condamine et al. 2013). The DEC analysis were performed using Lagrange in the program RASP 3.03 (Yu et al. 2011; Yu et al. 2015). Among their advantages, the use of DEC model allows that a specific clade may be present in more than one area or geographic range. Additionally, it generates stratified models, where distinct geographical connections are configured in relation to specific time slices of the analysis interval. According to this, we divided our paleobiogeographical model, which covers a temporal frame of 90 million years ago (since the upper Cretaceous to present), in 30 temporal intervals defined by geological, paleoclimatological studies and information based in intercontinental biotic interchanges in taxa such as mammals or plants (Fig.S5), the time span of these time slices varied between 1 and 5 million years. Following the method (Ree and Smith 2008), we established temporal constraints on the dispersal rates between areas; these constraints were based on the relative position of continents through time (references in Fig.S5). We defined four evolutionary models with specific constraints on the dispersal rates; each model was defined taking into account the possible dispersal rates between areas according with their relative position, geological barriers, land bridges presence and the distance between areas in each time bin. Considering this, we configured each model for the 30 time slides as follow: In absence of any barriers, the dispersal rate between adjacent areas was established as 1.0 for all the models. Then it was created three different configurations where the dispersal rates between landmasses separated by a maximum of 2,000 km were set to 0.5, 0.25 and 0.1 (for instance, Africa and Madagascar or Australia and New Zealand today). This 2,000 km limit was established in the remotest island colonized by birds (Tristan da Cunha Islands)(Holdgate 1965). Finally, we used two dispersal rates between landmasses further than 2,000 km: 0 or 0.1 (Condamine et al. 2013). According to these, the models were defined as: 1-0.1-0 Model, 1-0.5-0 Model, 1-0.25-0.1 Model and 1-0.5-0.1 Model (from the most conservative to the more flexible setup).

Using 10 areas would translate into 1024 (2^{10}) possible area combinations. This is beyond the DEC model computational limit and, we constrained the occupancy of certain areas combinations because the relative position of some continents suggest biological implausibility (Ree and Smith 2008; Condamine et al. 2013). Likewise, the different clades of birds present clear differences in their flying capacity and dispersal (De Queiroz 2005; Thorup 2006; Rolland et al. 2014; Pelegrin et al. 2015). For this reason and for computational viability, we carried out specific analyses to reconstruct the ancestral area in each one of 10 high-level clades according with Jarvis et al. (2014) (Palaeognathae, Galloanseres, Columbea, Otidimorphae, Caprimulgimorphae, Gruiformes, Charadriiformes, Aequornithes, Afroaves and Australaves), and evaluate their evolution under each dispersal scenario. Finally, with the results for each clade we performed a general analysis for Neornithes considering the diverse models. The optimal root area proposed by the model that better explains the distribution patterns was determined by comparison between likelihoods scores in each model considering significant differences when final likelihood score (f) was greater than or equal to two log-likelihood units, for -lnL values this implied lowest values (Condamine et al. 2013).

The reconstruction process of biogeographic ancestral occupancy combines all the information (living species geographic distribution, the tree topology, fossil record of recent and extinct lineages and the availability of connections among continents through time) and yields the likelihood values for each biome combinations in each node. Lagrange output for ten-areas analyses is complex. In order to organize the results and obtain the general paleobiogeographic patterns, we established a criterion based in the selection of the continent configurations with highest probability results for each node, which were organized decreasingly according to their likelihood value. The probability scores for these landmasses combinations were cumulative until a value of 0.5 was reached. The relative likelihood scores of each continent within these combinations were summed and all continents with a cumulative likelihood of more 0.25 were retained for each node (Tables S3-S14). For example, if for a node the most probable landmasses combinations are ST (presence in South America and Antarctica) with a likelihood value of 0.35, and SN (presence in South America and North America), with 0.15, this would imply that the values of relative probability for each continent are defined as follows: T= 0.35, S=0.50 and N=0.15. We would then

consider that only landmasses S and T are robustly reconstructed for that particular node.

According to the likelihood values for each model, we selected the optimal model to explore the colonization dynamics along the avian evolution in each continent. Then, we established the colonization events that explain the nodes states along the branches of the tree; the colonization events inferred by recent and extinct groups (considering fossil evidences) were integrated together. However, these events have a temporal uncertainty related with the moment of colonization, which might have happened in any instant along the branch or, in the case of fossil branches, their presence indicates the upper limit of possible colonization. Likewise, the phylogeny presents a trend to increase the amount of branches along time producing an important bias towards present. To solve this, we analysed the continental colonization through time using a sliding window method (Meredith et al. 2011; Wang et al. 2012). Through this approach we calculated the mean and the confidence interval of colonization rate from/towards each continent in 1 million years time intervals and smoothed with a 5 million years sliding window that considers the proportion of lineages in each period.

3.4. RESULTS

The likelihood scores and the root occupancy reconstructions for the four different evolutionary models are summarized in Tables 1 and 2. Detailed paleobiogeographical reconstructions for each clade under each model are shown in Fig. S1-S4 and the likelihood estimates for each node with their relative values until 50% in Table S3 to Table S13 (Appendix 3.8). The results for Neornithes (tree root) showed that less restrictive scenarios for dispersal (1-0.25-0.1 and 1-0.5-0.1 models) presented the highest likelihood values without significantly differences. The 1-0.5-0.1 model presented highest likelihood values in 7 clades, while the 1-0.25-0.1 model showed high likelihood in only 2 clades. However, there were statistical similarities among models for diverse groups. For instance, in Palaeognathae, Gruiformes and Australaves, the 1-0.5-0.1 model do not differ significantly from the 1-0.5-0, whereas for Galloanseres, Columbea and Caprimulgimorphae the 1-0.25-0.1 model was statistically similar to 1-0.5-0.1 model. Finally, all the models performed similarly in

Otidimorphae. Due to the statistical significance and the higher likelihood values in the majority of groups, we chose the 1-0.5-0.1 model as the most representative model. Fig. 1A and 1B, summarized our findings and colonization events following this model (1-0.5-0.1). This model proposes an origin of Neornithes in South America. Despite the likelihood differences, other scenarios such as the 1-0.25-0.1 and 1-0.1-0 models also proposed South America or Gondwana respectively as the origin area and possible centre of radiation for Neornithes.

The pattern of historical occupancy and dispersals remained similar across clades and models (Table 2). Our results suggest that ancestors of Otidimorphae and Australaves presented an initial diversification in the Southern Hemisphere, while the ancestors of other bird lineages would have diversified after colonizing the Northern Hemisphere. According with the best model, different pulses of colonization events to North America from South America during the late Cretaceous made possible the subsequent expansion of basal lineages across Asia. Furthermore, the South American proximity with Africa and Antarctica probably allowed the colonization and evolution in these continents and the subsequent expansion towards Europe across Africa, and to Australia and Zealand from Antarctica. This pattern suggests that during the initial evolutionary history of birds, North America, Africa and Antarctica probably were used as dispersal routes towards Asia, Europe and Australia respectively (Fig. 1A and 1B.).

The analysis of colonization rates (Fig.2) for each continent showed a high colonization rate of North America, Europe, Africa and Zealand during the first half of the upper Cretaceous. Other continents such as Australia, India and Madagascar presented peaks in their colonization patterns around 80 Ma. Conversely, Asia and South America presented low colonization rates during this period. In spite of their differences, all the continental patterns reflected a substantial decrease in the colonization rates around the latest Cretaceous, except for South America. During the Paleocene there were important stages of increasing colonization rate, which were intensified further during the early Eocene. Finally, around the Oligocene-Miocene boundary were registered new maximum values for colonization rates in all the continents.

3. Paleobiogeographical history

Table 1. Likelihood for paleobiogeographic analyses (-ln l) i=initial likelihood; f=final likelihood for the bird clades in each evolutionary model. Bold numbers are the lowest values of –lnL (high probability). Red values don't present significant differences respect to the lowest values, the significantly support was considered when differences greater than or equal to two log-likelihood units (Ree and Smith 2008).

Clade	1-0.5-0.1	1-0.25-0.1	1-0.5-0	1-0.1-0
Palaeognathae	i=31.38 **f=30.51**	i=32.74 f=32.21	i=30.28 **f=28.89**	i=34.73 f=32.05
Galloanseres	i=114.87 **f=113.56**	i=118.30 **f=115.01**	i=124.79 f=120.01	i=145.24 f=128.69
Columbea	i=58.98 **f=55.01**	i=60.72 **f=54.45**	i=71.59 f=59.53	i=86.57 f=62.44
Caprimulgimorphae	i=79.66 **f=77.75**	i=82.62 **f=78.85**	i=88.36 f=83.10	i=104.76 f=90.72
Otidimorphae	i=29.05 **f=22.14**	i=31.23 **f=21.94**	i=31.85 **f=22.43**	i=39.86 **f=22.84**
Gruiformes	i=65.82 **f=62.86**	i=69.94 f=64.93	i=68.60 **f=63.06**	i=81.80 f=70.20
Charadriiformes	i=150.80 **f=146.46**	i=158.98 f=149.94	i=165.68 f=152.71	i=201.22 f=169.08
Aequornithes + Phaethontimorphae	i=231.54 **f=218.21**	i=244.24 f=222.00	i=284.65 f=245.21	i=359.03 f=273.22
Afroaves	i=241.596 **f=239.164**	i=254.078 f=248.211	i=257.082 f=247.633	i=308.383 f=277.578
Australaves	i=77.18 **f=72.98**	i=82.02 f=75.61	i=88.81 **f=73.09**	i=112.66 f=83.30
Neornithes	i=92.12 **f=87.42**	i=97.57 **f=87.31**	i=112.44 f=95.65	i=144.73 f=102.91

Table 2. Areas defined for bird high-clades according with the four evolutionary models used. (A= Asia; E= Europe; F= Africa; I=India; M= Madagascar; N= North America; S= South America; T = Antarctica; U= Australia; Z= Zealand). For more details about the data and analyses see Supplementary Tables in Appendix 3.8.

Clade	1-0.5-0.1	1-0.25-0.1	1-0.5-0	1-0.1-0
Palaeognathae	NE SZF	N SZF	N SZF	N SZF
Galloanseres	NE SU	NE SU	NE SU	NE SU
Columbea	E SUM	E SUM	 SFUM	 SUM
Caprimulgimorphae	E S	E S	E S	EA S
Otidimorphae	 SFIM	 SFIM	 SFIM	 SFIM
Gruiformes	NE SFZ	NE SFZ	NE FZ	N SZ
Charadriiformes	NEA SFU	NEA SFU	NEA SFU	EA SFU
Aequornithes + Phaethontimorphae	NA STZ	N STZ	N STZ	N STZ
Afroaves	E F	NE F	E F	E F
Australaves	 STU	 STU	 STU	 STU
Neornithes	 S	 S	NEA SFT	 STUZ

3.5. DISCUSSION

3.5.1. Origin and early diversification in Neornithes.

The development of a prominent flying capacity in early birds during the begging of their evolutionary history allowed them to move efficiently across diverse environments and to avoid ecologically hostile conditions respect to other land animals (Chiappe and Dyke 2006). Moreover, the evolution of long-distance dispersal capacities was key in the dispersal of bird lineages through continents. This is agreement with our results, which suggest models with higher dispersal rates (1-0.5-0.1 and 1-0.25-0.1) as the better-fits to the data. The differences observed in the likelihood values for the clades probably have relationship with the development of an aerodynamic morphology and diverse physiological mechanisms for the flight energy efficiency (Hedenström 2010), which depends on each clade historical particularities. These characteristics and different dietary specializations possibly constituted as important adaptations for the evolution of diverse flight strategies allowing the initial morphological and ecological differentiation between avian lineages (Mitchell and Makovicky 2014). Likewise, these traits would have constitutes as exaptations (Gould and Vrba 1982) for achieved prominent dispersal capacity over long distances and even during independent moments of the avian history allowing the evolution of migratory behaviour (Alerstam et al. 2003; Piersma et al. 2005).

The models with highest probabilities estimate the origin of Neornithes in South America during the Upper Cretaceous (about 101 Ma), which is in line with fossil evidences (Agnolin and Novas 2012). The results showed an evolutionary scenario with diverse colonization events from South America during the upper Cretaceous. These patterns probably are related with the initial proximity between South America and the other Gondwanan landmasses enabling their colonization by early lineages and their succeeding expansion. Gondwana started its break around 180 Ma (Scotese et al. 1999) and the effect of plate tectonics in the configuration of landmasses determined the arising of many vicariance processes and opportunities for biotic exchange in the southern continents (Rage 1988; Cracraft 2001; Givnish and Renner 2004; Limolino et al. 2010). In this way, the relative closeness and the continuous fragmentation process probably were key factors in the colonization processes of early lineages with different

dispersal capacities, which allowed parallel evolution and different diversification patterns (Claramunt et al. 2012).

3.5.2. Palaeognathae historical biogeography

Considering the Palaeognathae early evolution (Fig.1A), our findings showed a dispersal process along the upper Cretaceous reaching a broad distribution towards Africa and Zealand in Southern latitudes, as well as North America and Europe. About 100 Ma Africa separated from South America and during this time probably the ancestors of African and Northern Hemisphere ratites invaded Africa (Ezcurra and Agnolin 2012). Furthermore, land connection between South America and Antarctica persisted until the Drake opening during the late Eocene and probably many lineages may colonized Zealand during the middle Upper Cretaceous through Antarctica (Laird and Bradshaw 2004). According to this, our findings are consistent with the Gondwanan origin and diversification of Ratites (van Tuinen et al. 1998; Cracraft 2001; Johnston 2011) with successive colonizations of the Northern Hemisphere during diverse periods. These colonizations probably were possible for medium-size lineages that reached Europe via Africa and further North America using the De Geer route (Brikiatis 2014). This is evidenced in the Northern Hemisphere by the presence of extinct ratite lineages such as Palaeotididae and Lithornithidae in Northern Hemisphere (Mayr 2009; Stidham et al. 2014b). For the case of Lithornithidae, diverse anatomical features have suggested that probably had the ability to perform sustained flight associated to a semi-aquatic niche (Houde 1988; Mayr 2009). Which is also consistent with convergent development of flightlessness from flying ancestors during ratites history due probably to the isolation and low predation pressure (Phillips et al. 2009; Baker et al. 2014).

3.5.2. Galloanseres historical biogeography

During the Upper Cretaceous, Galloanseres ancestors dispersed across North America, Europe and Australia (Fig.1A). The colonization process from South America to North America might allow the further colonization of Europe using the De Geer route and land bridges that connected the Euramerica stage (Sanmartín et al. 2001; Pereda-Suberbiola 2009; Ezcurra and Agnolin 2012). Likewise, Antarctica probably was an important route towards Australia. The broad extension that early Galloanseres reached in the Northern and Southern Hemispheres suggest that extinct lineages such

as Pelagornithidae already had an important fly capacity (Mayr 2011a). Recent groups such as Anseriformes have even developed migratory behaviour, which has been key in their evolutionary success (Dalby et al. 2014). The isolation process in two continental scenarios could make possible the vicariance and evolution of Galloanserae basal forms (Gastornithidae and Pelagornithidae) and the subsequent evolution of Galliformes in the Northern Hemisphere (Mayr 2009), while Anseriformes ancestors expanded across the Southern Hemisphere, evolving in South America and Australia. This is in agreement with the presence of Anseriformes fossil evidence in Antarctica (Clarke et al. 2005b), and the prominent presence of basal lineages of Anseriformes in the Southern Hemisphere, such as Anhimidae, Anseranatidae and Dromornithidae families (Murray and Megirian 1998; Alvarenga 1999). In the Anatidae case, basal groups such as Dendrocygninae, and diverse tribes such as Malacorhynchini, Stictonettini, Cereopseini also occur in the Southern Hemisphere (Eo et al. 2009; Del Hoyo and Collar 2014). We observed an early dispersion of Anseriformes towards the Northern Hemisphere during the Paleocene, while early Galliformes were restricted to Europe forests during the Paleocene. These patterns may propose a biogeographic history related with the development of flying and body size specializations. In the case of Gastornithidae and Pelagornithidae, the differentiation in niche preferences by body size probably drove to the divergence process between their ancestors from the other Galloanseres, these lineages reached large body sizes with land and aquatic life respectively (Angst et al. 2014; Ksepka 2014). On the other hand, Galliformes in the Northern Hemisphere might have adapted to the forest life style and probably have evolved towards flightlessness condition (Mayr 2009) caused by the absence of larger terrestrial predators after the extinction of dinosaurs (van Valkenburgh 1999; Mayr 2009). These conditions, and the tropical island environments in Europe might have triggered the basal diversification of Galliformes in many stem lineages during the Paleocene (Mayr 2005b). Meanwhile, the Anseriformes probably preserved the flying capacities associated probably with a semiaquatic lifestyle, which enabled them to disperse from the South Hemisphere to North America and Eurasia during the latest Cretaceous and Paleocene (Kurochkin et al. 2002; Mayr 2009). Finally, in Galliformes the colonization events by crown clades towards southern continents would be later to the basal radiation in the Northern Hemisphere. Diversification of modern crown lineages during the late Eocene and Oligocene probably was triggered by the climate changes that transformed the warm and forested global environments in cooler,

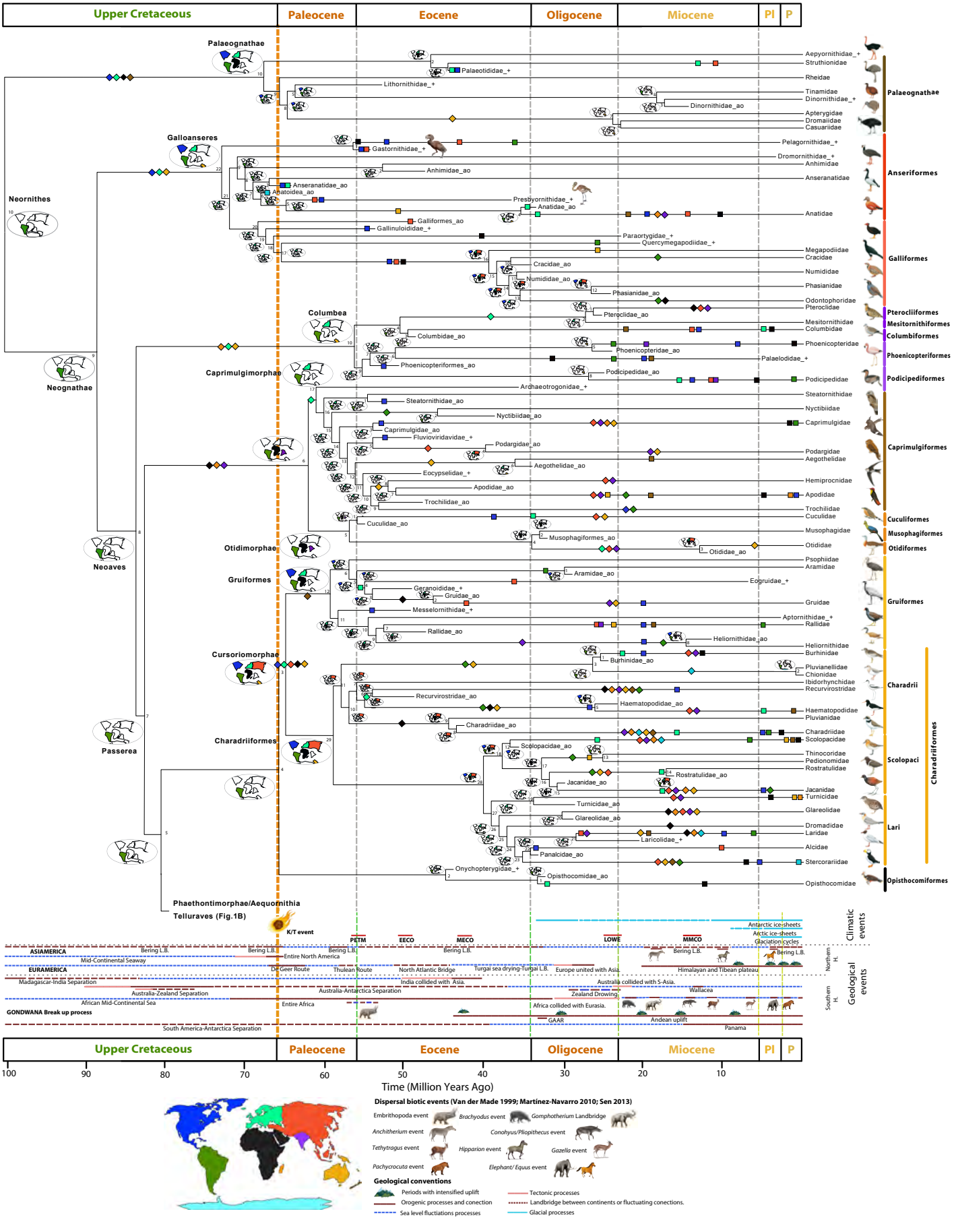
seasonal and arid habitats (Zachos et al. 2001; Edwards et al. 2010), which may favoured their diversification in the Old World and North America (Mayr 2005b, 2009; Mourer-Chauviré et al. 2011) (see more discussion and details in Chapter 3). Therefore, our findings for crown Galliformes are inconsistent with the Gondwana break-up as predominant mechanism that promoted the vicariance and evolution in Galliformes as proposed by Cracraft (2001).

3.5.4. Columbea historical biogeography

During the latest Cretaceous, different dispersal episodes from South America enabled a broad geographical distribution in diverse ancestors of Neoaves clades. Due to subsequent isolation, these clades diversified by parallel evolution in diverse lineages adapted to the particular conditions of each continent. Columbea evolution presented an initial dispersion from South America towards Europe and Australia during the upper Cretaceous. This reconstruction suggests a possible dispersal route through Africa and Antarctica. The dispersion across Africa and Madagascar is evidenced also in Caprimulgimorphae and Otidimorphae ancestors. These patterns seems to indicate that during the latest Cretaceous and the Paleocene, Africa played an important role as a dispersion route from South America towards Europe (Ezcurra and Agnolin 2012), where Columbea ancestors developed a significant diversity along the Paleocene and Eocene (Mayr 2009). These findings are consistent with interchange events reported in mammals such as the Embrithopoda event (Sen 2013).

Phoenicopterimorphae evolution was associated with an isolation process in Europe respect to Australia, this process might generated an important diversity of flamingo-like species (Mayr 2009, 2014a), probably associated to aquatic and semiaquatic conditions in the tropical and insular Eocene Europe (Mayr 2011c).

Figure 1A. Paleobiogeographical patterns in Neornithes according with the 1-0.5-0.1 Model using Lagrange (DEC). The continental colonization events that explain the inferred area(s) with the highest relative likelihood (in the nodes) respect to present-day distributions is indicated by coloured rhombus and squares. Rhombus, in the middle of the clade indicate the theoretical colonization, if exist fossil supports for events, these are indicated with squares according to the fossil calibration and date (see references in Appendix 3.8. Table S1 and S2).


Upper Cretaceous
Paleocene
Eocene
Oligocene
Miocene
Pl
P
Palaeognathae
Galloanseres
Neornithes
Neognathae
Columbea
Caprimulgimorphae
Otidimorphae
Neoaves
Gruiformes
Cursoriomorphae
Charadriiformes
Passerea
Phaethontimorphae/Aequornithia
Telluraves (Fig.1B)
Aepyornithidae_+
Struthionidae
Palaeotididae_+
Rheidae
Lithornithidae_+
Tinamidae
Dinornithidae_+
Dinornithidae_ao
Apterygidae
Dromaiidae
Casuariidae
Gastornithidae_+
Pelagornithidae_+
Dromornithidae_+
Anhimidae
Anhimidae_ao
Anseranatidae
Anseranatidae_ao
Anatoidea_ao
Presbyornithidae_+
Anatidae_ao
Anatidae
Galliformes_ao
Gallinuloididae_+
Paraortygidae_+
Quercymegapodiidae_+
Megapodiidae
Cracidae
Cracidae_ao
Numididae
Numididae_ao
Phasianidae
Phasianidae_ao
Odontophoridae
Pteroclidae
Pteroclidae_ao
Mesitornithidae
Columbidae
Columbidae_ao
Phoenicopteridae
Phoenicopteridae_ao
Palaelodidae_+
Phoenicopteriformes_ao
Podicipedidae_ao
Podicipedidae
Archaeotrogonidae_+
Steatornithidae
Steatornithidae_ao
Nyctibiidae
Nyctibiidae_ao
Caprimulgidae
Caprimulgidae_ao
Fluvioviridavidae_+
Podargidae
Podargidae_ao
Aegothelidae
Aegothelidae_ao
Eocypselidae_+
Hemiprocnidae
Apodidae
Apodidae_ao
Trochilidae
Trochilidae_ao
Cuculidae
Cuculidae_ao
Musophagidae
Musophagidae_ao
Otididae
Otididae_ao
Psophiidae
Aramidae
Aramidae_ao
Eogruidae_+
Geranoididae_+
Gruidae
Gruidae_ao
Messelornithidae_+
Aptornithidae_+
Rallidae
Rallidae_ao
Heliornithidae
Heliornithidae_ao
Burhinidae
Burhinidae_ao
Pluvianellidae
Chionidae
Ibidorhynchidae
Recurvirostridae
Recurvirostridae_ao
Haematopodidae
Haematopodidae_ao
Pluvianidae
Charadriidae
Charadriidae_ao
Scolopacidae
Scolopacidae_ao
Thinocoridae
Pedionomidae
Rostratulidae
Rostratulidae_ao
Jacanidae
Jacanidae_ao
Turnicidae
Turnicidae_ao
Glareolidae
Glareolidae_ao
Dromadidae
Laridae
Laricolidae_+
Alcidae
Panalcidae_ao
Stercorariidae
Onychopterygidae_+
Opisthocomidae_ao
Opisthocomidae
Palaeognathae
Anseriformes
Galliformes
Pteroclifformes
Mesitornithiformes
Columbiformes
Phoenicopteriformes
Podicipediformes
Caprimulgiformes
Cuculiformes
Musophagiformes
Otidiformes
Gruiformes
Charadrii
Scolopaci
Lari
Charadriiformes
Opisthocomiformes
K/T event
PETM
EECO
MECO
LOWE
MMCO
Climatic events
Antarctic ice-sheets
Arctic ice-sheets
Glaciation cycles
Geological events
ASIAMERICA
EURAMERICA
GONDWANA Break up process
Bering L.B.
Mid-Continental Seaway
Entire North America
De Geer Route
Thulean Route
North Atlantic Bridge
Turgai sea drying-Turgai L.B.
Europe united with Asia.
Himalayan and Tibean plateau
Madagascar-India Separation
India collided with Asia.
Australia collided with S-Asia.
Australia-Zealand Separation
Australia-Antarctica Separation
Zealand Drowing
Wallacea
African Mid-Continental Sea
Entire Africa
Africa collided with Eurasia.
GAAR
Andean uplift
South America-Antarctica Separation
Panama
Northern H.
Southern H.
100
90
80
70
60
50
40
30
20
10
Time (Million Years Ago)
Dispersal biotic events (Van der Made 1999; Martínez-Navarro 2010; Sen 2013)
Embrithopoda event
Brachyodus event
Gomphotherium Landbridge
Anchitherium event
Conohyus/Pliopithecus event
Tethytragus event
Hipparion event
Gazella event
Pachycrocuta event
Elephant/ Equus event
Geological conventions
Periods with intensified uplift
Orogenic processes and conection
Sea level fluctiations processes
Tectonic processes
Landbridge between continents or fluctuating conections.
Glacial processes

Conversely, the early evolution of Columbimorphae was structured by the development of Columbiformes lineages in South America and Australia, and Pterocliformes in Europe. The relictual presence of Mesitornithiformes in Madagascar, sister group of Pterocliformes, is an interesting indicator of the Old World evolution of this clade. The southern evolution of Columbiformes is consistent with the broad presence of basal lineages in South America (Johnson and Clayton 2000a, b) and the prominent diversification that doves present in Southern Pacific islands near Australia (Cibois et al. 2014). On the other hand, Pterocliformes would have dispersed from Europe to Africa and Asia during the Neogene probably in concomitancy with many interchange events reported in mammals (van der Made 1999). These findings agree with the adaptation of Pteroclidae species to arid conditions (Hinsley et al. 1993), which increased during the Late Oligocene and established the beginning of a generalised aridification process in the Earth (Zachos et al. 2001; Edwards et al. 2010).

3.5.5. Caprimulgimorphae and Otidimorphae historical biogeography

The evolution of Caprimulgiformes was associated with the colonization of Europe by ancestral forms. Our reconstruction suggests that the adaptive radiation of the clade took place in Europe during the Paleocene. The archipelago condition of Europe and its tropical climate might facilitated the diversification of the Caprimulgiformes during the Paleocene and early Eocene (Mayr 2011c), and subsequent dispersion of multiple lineages from Europe towards North America and Asia using the Thulean route (Lindow and Dyke 2006; Brikiatis 2014) or through the Turgai Strait respectively. These colonization events were key in the diversification of Caprimulgiformes taxa across the world. Likewise, the development of a sophisticated flying capacity and even migratory strategies would be crucial in the dispersion of Caprimulgidae and Apodidae worldwide (Barrowclough et al. 2006; Thomassen 2005; Larsen et al. 2007; Päckert et al. 2012).

During the Paleocene and Eocene, European avifaunas evolved in an archipelago with tropical conditions (Lindow and Dyke 2006). Under this scenario occurred the early diversification of Caprimulgiformes lineages (Fig.1A) (Larsen et al. 2007; Braun and Huddleston 2009). The extinction of European lineages around the Eocene-Oligocene boundary probably was triggered by the confluence of diverse factors such as climatic events (Francis et al. 2008), which affected the plant physiognomy of

tropical environments in the Northern Hemisphere (Lindow and Dyke 2006) as well as species with high dependency of their resources for feeding or nesting such as Trochilidae, Nyctibidae and Aegothelidae. During this period, some lineages of these families relocated their distribution towards tropical environments in the south of North America and Asia, making possible the ulterior colonization of South America and Australasia respectively. Likewise, the differential extinction of European forms respect to others also might have relationship with the biotic interchange between Asia and Europe during the closure of Turgai Strait. According with Mayr 2011c, during the Grande Coupure turnover (Stehlin 1909) entered in Europe new mammalian taxa such as muroid rodents and carnivorans (felids and viverids), this new predation pressure would have affected significantly the unadapt nesting strategies in European lineages that evolved in isolated conditions (Mayr 2011c). This is also in line with the last occurrence of flightless lineages in Europe (Mayr 2009). This ecological process has been reported in modern insular environments, which the predation by mammals and snakes is the main cause of extinction in avian populations (Blackburn et al. 2004).

Ancestors of Otidimorphae dispersed across South America, Africa, Madagascar and India. Subsequently, our findings propose an early divergence between Cuculiformes and Otidiformes-Musophagiformes, which remained restricted to Africa. Conversely, the wide geographical distribution of the early Cuculiformes allowed their spread towards the Northern Hemisphere. This is in line with the presence of cuckoos with terrestrial habits in Madagascar and Indomalaysian, *Coua* and *Carpococcyx* respectively (Hughes 1996; Posso and Donatelli 2012). These basal lineages probably conserved the terrestrial condition due to long isolation and the low predation pressures that suffer Madagascar and the Indian subcontinent. This relationship between Malagasy and Indian faunas has been observed in many taxa (Yoder and Nowak 2006; Warren et al. 2010). Later, the Indian lineages colonized the Southern Asian habitats when both continents contacted each other. Therefore, the presence of Cuculidae in North America, Eurasia and Australia is a derivate condition, likely due to diverse colonization events from South America, Africa and Southern Asia (Posso and Donatelli 2012), which is consistent with the fossil record for Cuculidae (Baird and Vickers-Rich 1997).

The evolutionary patterns for Otidiformes and Musophagiformes suggest that during the Oligocene both groups diverged in Africa. This process probably is related

to ecological specialization. While the Musophagiformes lineages evolved in close association to forested environments (Turner 1997), the bustard lineages developed adaptations to open and arid conditions (Williams and Tieleman 2001). The increasing aridification since the late Oligocene generated ecosystems such as grasslands and savannas that took preponderance in the landscapes (Zachos et al. 2001; Jacobs 2004; van Dam 2006; Senut et al. 2009), which probably favoured the spread of Otididae across the Old world during the Neogene (Sánchez Marco 1990; Mlíkovský 2002). Meanwhile Musophagidae only entered in Europe during the middle Miocene, probably associated with dry seasonal forested environments (Mayr 2011c).

3.5.6. Opistocomiformes and Cursoriomorphae historical biogeography

Opistocomiformes ancestors evolved restricted to South America with a later colonization of Africa and Europe (Mayr et al. 2011), which indicates that possibly the interchange capacity between South America and Africa persisted until the Oligocene (Ezcurra and Agnolin 2012). Similar biotic interchanges across the Atlantic have been proposed for different taxa, even for animals with a presumable low dispersal capacity, as the ancestors of New World monkeys (Bond et al. 2015), caviomiorph rodents (Poux et al. 2006; de Oliveira et al. 2009), as well as diverse fish and lizard lineages (Lundberg et al. 2007; Vidal et al. 2008).

On the contrary, Cursoriomorphae ancestors dispersed from South America, achieving a broad geographical distribution in a relative brief time span just after the Cretaceous – Paleogene boundary (Fig.1A). This suggests an early development of more efficient flying capacity, which probably arose in relation with the adaptation to aquatic and semiaquatic life style and omnivorous dietary habits (Pelegrin et al. 2014). Moreover, the K/T event would have affected the occupancy of ecological niches due to the extinction of aquatic birds such as Hesperornithiformes or Ichthyornithiformes restricted to the Northern Hemisphere (Chiappe and Dyke 2002; Clarke 2004; Wilson et al. 2011). Due to the geographical focus of K/T event, probably the climatic changes and their environmental consequences were more intense in northern latitudes respect to Southern Hemisphere (Archibald et al. 2010; Schulte et al. 2010).

The broad distribution reached by Charadriiformes ancestors allowed subsequent vicariance processes and the parallel evolution of different clades in different continents. Despite, the inference difficulties associated to wide geographical

distributions achieved by many clades along their evolutionary history (Mayr 2011b), fossil evidences and geographical distributions for basal groups shed light on the paleobiogeographical pattern of Charadriiformes. Charadrii diversificated during the Eocene in Asia presented later dispersal events in direction to Europe and Australia. Probably, isolation mechanisms favoured the evolution of two main lineages: Recurvirostridae-Haematopodidae-Charadriidae in the Northern Hemisphere, and Burhinidae-Chionidae-Pluvianellidae that diversified during the Late Oligocene in the Southern Hemisphere (Paton et al. 2003; Livezey 2010).

During the late Eocene the Scolopaci lineages diverged in a Northern Hemisphere lineage conformed by Scolopacidae, and a Southern clade that diversified through Africa (i.e Jacanidae) and colonized other Southern territories (Pedionomidae and Thinocoridae) during the Late Oligocene. These patterns coincide with the observed for the Burhinidae clade, which might suggest a key link with Antarctica isolation, global cooling and lower sea levels during the Oligocene (Zachos et al. 2001; Paton et al. 2003; Francis et al. 2008).

The obtain patterns for Charadrii and Scolopaci are broadly consistent with the biogeographical scenario proposed by Livezey 2010, explain the relative high intense effect of global climate changes in the Northern Hemisphere respect to Southern continents. The Holarctic lineages suffered diverse process of southward expansions and northward retreats in their distributions due to climatic changes probably promoting the migratory habits. Meanwhile, the distribution of landmasses in southern latitudes limited the impact of glaciations, except for Antarctica. This polar dichotomy reflected the relative abundance and diversity of migratory lineages northwards, while in the southern latitudes are predominately resident or short-distance migratory (Livezey 2010).

Lari patterns suggest that the radiation processes of gulls and allies probably took place in Europe (De Pietri et al. 2011). Under this context, the outstanding diversification of different lineages in Lari can be explained considering the environmental context during the middle and late Eocene. During this time, Europe was still an archipelago and existed a connection route between the western Tethys and the Arctic Sea via Turgai Strait, which enabled the establishment of a warm climate in Europe (Rögl 1999). Two factors might play a key role in the diversification of Lari as

marine birds in Europe. First, during the middle Eocene there were important peaks in diversity of marine fishes (i.e Tuna lineage), which constituted an important food supply (Near et al. 2013). Secondly, the absence of marine mammals such as seals and sea lions, which did not appear until the late Oligocene (Churchill et al. 2015), allowed the occupancy of sea niches without ecological competition. Therefore, marine environments possibly represented a source of adaptive zones, which favoured process of ecological differentiation and available diversification of major Lari lineages. Laridae and Laricolidae diversification was predominant during the Oligocene and Miocene; while dispersal capacity and generalist diet requirements allowed to Laridae the colonization of all continents during the Miocene (Worthy et al. 2007), Laricolidae remained associated to European marine environments (De Pietri et al. 2011), which suffered substantial changes during the Oligocene and Miocene (Rögl 1999). In relation to Alcidae and Stercorariidae, our results suggest that their split process was triggered by the Eocene-Oligocene climate transition (Smith and Clarke 2014). During this period, environmental changes affected the ocean latitudinal temperature gradients and caused the development of diverse levels of thermal tolerance by Pan-alcidae ancestors (Smith and Clarke 2014). These adaptations allowed them to diversify across the Northern Hemisphere oceans, with Mancalinae lineage towards the northern Pacific (Smith 2011) and Alcinae in the North Atlantic (Mlíkovský 2009; Smith and Clarke 2014). The divergence process of Stercorariidae probably is related with their ecological specialization such as fly-aquatic predator, respect to swimming and diving habits of Alcidae. The Stercorariidae adaptive zone promoted a broad geographic distribution reaching the temperate latitudes of Northern Hemisphere and subsequently colonizing the Southern Hemisphere during the Pleistocene (Ritz et al. 2008). Interestingly, the Northern Hemisphere families in the three charadriifom lineages would have developed migratory behaviour independently (Del Hoyo et al. 1996; Livezey 2010), which was an adaptive mechanism development probably from exaptation-type traits to cope the emergent seasonal regime (Piersma et al. 2005) caused by the global cooling process that Earth experimented since the Oligocene (Zachos et al. 2001).

Paleobiogeographical patterns of Gruiformes showed a divergence process between the New World and Old World lineages. The early evolution of the American lineage (Gruoidea) was associated with the isolation of North America from South

America. Within this group, the evolution of Psophiidae was constrained to South America (Ribas et al. 2011), meanwhile the diversification of other families took place in North America. Later, Aramidae would remain in North America, recolonizing South America via Panama landbridge during the Miocene (Montes et al. 2015). The colonization of Europe from North America during the early Eocene through the Thulean route (Brikiatis 2014), and successive dispersals toward Asia and Africa allowed the isolation of the lineages. Geranoididae diversified in Europe during the Eocene, while Eogruidae lineage could have colonized Asia across the Bering Landbridge or during the Grande Coupure event (Clarke et al. 2005a; Costa et al. 2011). Likewise, the closeness between Europe and Africa during the Eocene made possible the colonization of Africa by Gruidae ancestors probably during the Embrithopoda event (Sen 2013), consistent with the presence of basal Balearicinae cranes in Africa (Del Hoyo and Collar 2014).

Finally, the Old World lineage (Ralloidea) evolution was associated with African and European warm environments, predominant during the early Eocene (Prothero and Berggren 1994; Lindow and Dyke 2006; Mayr 2011c; Garcia-R et al. 2014). Later, changes in European climate during the Oligocene, confined basal lineages of Rallidae and Heliornithidae to Africa as evidenced by basal Sarothrurinae in Rallidae and *Podica* for Heliornithidae (Del Hoyo and Collar 2014). Likewise clades such as Messelornithidae colonized North America, during parallel periods respect to the European entry of Gruoidea. On the other hand, the isolated presence of Aptornithidae in Zealand suggests an early colonization process associated with the dispersal capacity developed by the cursoriomorpha ancestors. The broad capacity of dispersion in Ralloidea is supported by the high dispersion observed in the Rails, which are present even in the most remote islands of the Pacific, for instance *Zapornia* crakes (Del Hoyo and Collar 2014).

3.5.7. Phaethontimorphae and Aequornithia historical biogeography

The clade Phaethontimorphae-Aequornithia presents a great disparity of groups, which achieved a broad geographical distribution, probably related to their adaptation to marine life-style (Cody 1973; Warheit 1992; Davies et al. 2010). Our paleobiogeographic scenario for Phaethontimorphae and Aequornithia clade suggests an early adaptative evolutionary process that began during the upper Cretaceous, and

implies dispersal from South America to Asiamerica (Scotese 2001) and Zealand via Antarctica (Fig.1B). Apparently, the development of high dispersal flying capacity associated with the invasion of aquatic habitats was an important process that promoted the early diversification of Phaethontimorphae-Aequornithia clade before the K/T. In a similar way to Charadriiformes after K/T, these findings are consistent with the importance of dispersal capacities in the evolutionary patterns for aquatic birds suggest by several authors (De Queiroz 2005; Gillespie et al. 2011). This radiation during the middle late Cretaceous is coherent with the outstanding predominance of diverse aquatic and semiaquatic forms for Ornithurae lineages during the late Cretaceous (Chiappe and Witmer 2002; Longrich 2009). Conversely, along this time enanthiornithe birds dominated the terrestrial ecosystems until their extinction during the K/T event (Longrich 2009; Longrich et al. 2011; O'Connor et al. 2011).

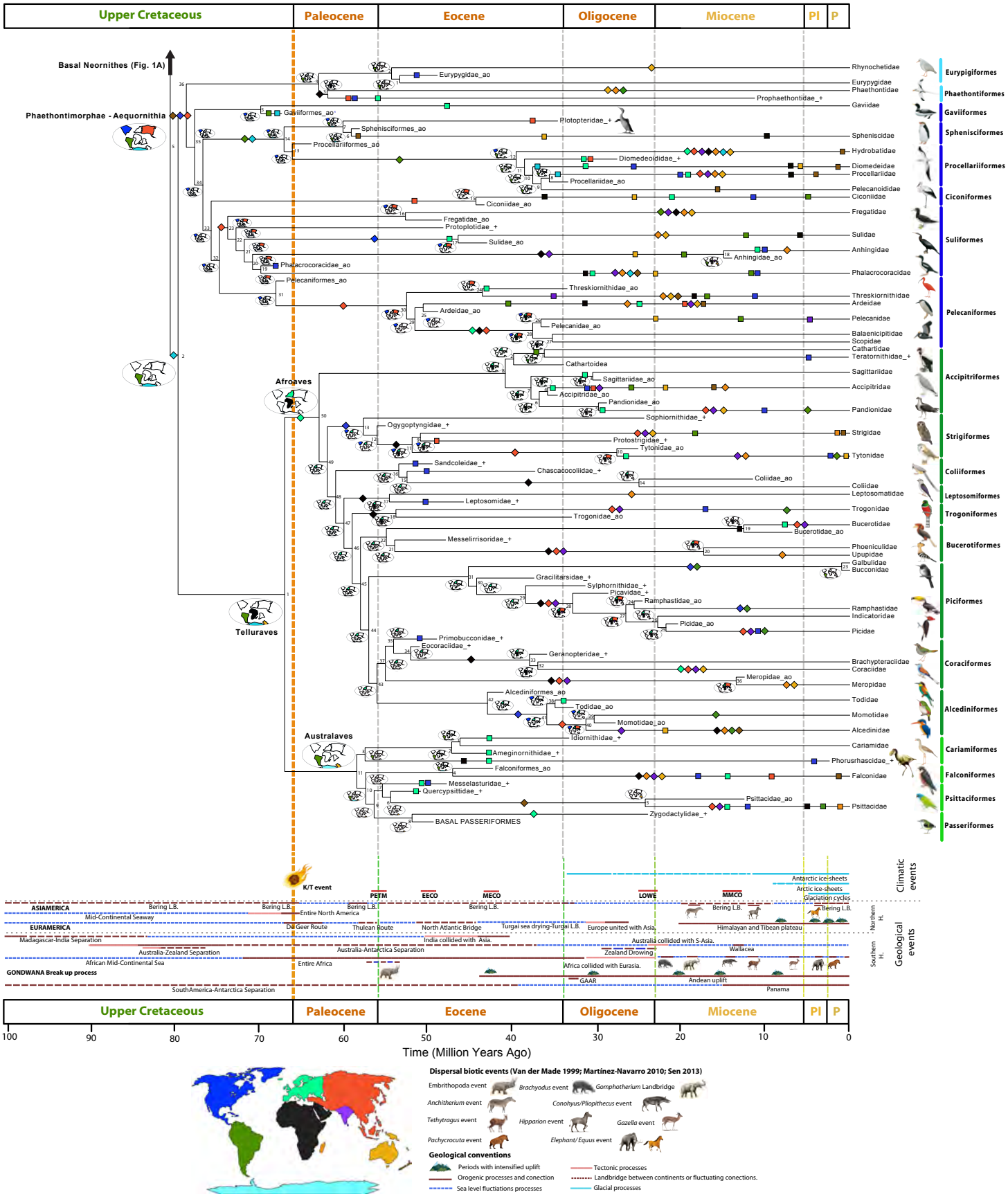
Worldwide distribution of early Phaethontimorpha-Aequornithes probably caused that some distant regions respect to the focus of the K/T bolide impact in North America (Schulte et al. 2010) may played a role as refugia of basal lineages. This could explain the extinction of many shore and marine bird species in the Northern Hemisphere as is reported in Hesperornithidae or Graculavidae lineages (Longrich et al. 2011; Wilson et al. 2011), while contrary Southern originated aquatic groups as basal Phaethotimorphae, Gaviiformes and Sphenisciformes-Procellariformes common ancestors were able to survive, which is also consistent with the observed patterns in Late Cretaceous basal Anseriformes (Clarke et al. 2005b). Likewise, our results suggest that the Ciconiformes-Suliformes-Pelecaniformes ancestor would have survived in Asia refugia.

Phaethontimorphae ancestors diversified in Africa with the arising of Prophaethontidae and Phaethontidae lineages (Bourdon et al. 2005; Mlíkovský 2009), whereas the Eurypigiformes ancestors evolved in South America. The spread of Phaethontiformes across different latitudes would play an important role in Phaethontidae evolution, which achieved a pantropical distribution while Prophaethontidae were restricted to the Northern latitudes where had to cope with the emerging of cool and seasonal conditions during the late Miocene (Zachos et al. 2001) and ecological competition due to the radiation of other marine birds such Laridae (Mayr 2015).

Early evolution of Gaviiformes, Sphenisciformes and Procellariiformes took place in the Southern Hemisphere associated with different adaptations to the marine life-style (Martin 1995), which separated these three main evolutionary lines (van Tuinen et al. 2001). Gaviiformes colonized the Northern Hemisphere (Mayr and Zvonok 2011) and disappeared from the Southern Hemisphere (Tambussi and Acosta Hospitaleche 2007). Sphenisciformes evolution was focused in the Southern Hemisphere (Ksepka et al. 2006) while Plotopteridae colonized the northern ocean habitats (Olson and Hasegawa 1996; Mayr 2009; Dyke et al. 2011). Early Procellariiformes diversification was mainly restricted to the southernmost latitudes. Some authors propose that the proliferation of isolated environments in islands promoted allopatric processes in the Southern Hemisphere, which influenced on the diversification of Procellariiformes (Chown et al. 1998; Davies et al. 2010). The low dispersion of Procellariiformes towards the Northern Hemisphere along the Paleocene and Eocene was probably due the ecological presence of other lineages with similar niches such as Suliformes, Phaethontiformes or Pelagornithidae, which dominated the marine ecosystems during the Eocene (Bourdon et al. 2005; Bourdon et al. 2008; Mlíkovský 2009). However, lineages such as Diomedeoididae and Diomedeidae were able to achieve northern latitudes during the Oligocene (Mlíkovský 2009; Mayr and Smith 2012).

Ciconiformes-Suliformes-Pelecaniformes diversified during the upper Cretaceous in marine environments from North America and Asia (Asiamerica), which was separated from Euramerica through mid-continental seaway (Sanmartín et al. 2001). Under this scenario, during the latest Cretaceous Suliformes diverged from Pelecaniformes probably in relationship with the adaptation to freshwater habitats by Pelecaniformes ancestors in North America, while the Suliformes would remain in Asian sea environments where diversified before K/T probably due to the absence of dominant sea bird lineages such as Hesperornithiformes, which were abundant in the Euramerica and Artic seas (Rees and Lindgren 2005; Bell and Everhart 2009).

Figure 1B. Paleobiogeographical patterns in Neornithes according with the 1-0.5-0.1 Model using Lagrange (DEC). The continental colonization events that explain the inferred area(s) with the highest relative likelihood (in the nodes) respect to present-day distributions is indicated by coloured rhombus and squares. Rhombus, in the middle of the clade indicate the theoretical colonization, if exist fossil supports for events, these are indicated with squares according to the fossil calibration and date (see references in Appendix 3.8. Table S1 and S2).


Upper Cretaceous
Paleocene
Eocene
Oligocene
Miocene
Pl
P
Basal Neornithes (Fig. 1A)
Phaethontimorphae - Aequornithia
Afroaves
Telluraves
Australaves
Eurypygidae_ao
Gaviiformes_ao
Sphenisciformes_ao
Procellariiformes_ao
Ciconiidae_ao
Fregatidae_ao
Protoplotidae_+
Sulidae_ao
Phalacrocoracidae_ao
Pelecaniformes_ao
Threskiornithidae_ao
Ardeidae_ao
Pelecanidae_ao
Cathartoidea
Sagittariidae_ao
Accipitridae_ao
Pandionidae_ao
Sophiornithidae_+
Ogygoptyngidae_+
Protostrigidae_+
Tytonidae_ao
Sandcoleidae_+
Chascacocoliidae_+
Coliidae_ao
Leptosomidae_+
Trogonidae_ao
Messelirrisoridae_+
Gracilitarsidae_+
Sylphornithidae_+
Picavidae_+
Ramphastidae_ao
Picidae_ao
Primobucconidae_+
Eocoraciidae_+
Geranopteridae_+
Meropidae_ao
Alcediniformes_ao
Todidae_ao
Momotidae_ao
Idiornithidae_+
Ameginornithidae_+
Falconiformes_ao
Messelasturidae_+
Quercypsittidae_+
Psittacidae_ao
Zygodactylidae_+
BASAL PASSERIFORMES
Rhynochetidae
Eurypygidae
Phaethontidae
Prophaethontidae_+
Gaviidae
Plotopteridae_+
Spheniscidae
Diomedeoididae_+
Hydrobatidae
Diomedeidae
Procellariidae
Pelecanoididae
Ciconiidae
Fregatidae
Sulidae
Anhingidae
Anhingidae_ao
Phalacrocoracidae
Threskiornithidae
Ardeidae
Pelecanidae
Balaenicipitidae
Scopidae
Cathartidae
Teratornithidae_+
Sagittariidae
Accipitridae
Pandionidae
Strigidae
Tytonidae
Coliidae
Leptosomatidae
Trogonidae
Bucerotidae
Bucerotidae_ao
Phoeniculidae
Upupidae
Galbulidae
Bucconidae
Ramphastidae
Indicatoridae
Picidae
Brachypteraciidae
Coraciidae
Meropidae
Todidae
Momotidae
Alcedinidae
Cariamidae
Phorusrhascidae_+
Falconidae
Psittacidae
Eurypigiformes
Phaethontiformes
Gaviiformes
Sphenisciformes
Procellariiformes
Ciconiiformes
Suliformes
Pelecaniformes
Accipitriformes
Strigiformes
Coliiformes
Leptosomiformes
Trogoniformes
Bucerotiformes
Piciformes
Coraciformes
Alcediniformes
Cariamiformes
Falconiformes
Psittaciformes
Passeriformes
K/T event
PETM
EECO
MECO
LOWE
MMCO
Climatic events
Antarctic ice-sheets
Arctic ice-sheets
Glaciation cycles
Geological events
ASIAMERICA
EURAMERICA
GONDWANA Break up process
Bering L.B.
Mid-Continental Seaway
Entire North America
De Geer Route
Thulean Route
North Atlantic Bridge
Turgai sea drying-Turgai L.
Europe united with Asia
Himalayan and Tibean plateau
Madagascar-India Separation
India collided with Asia.
Australia collided with S-Asia.
Australia-Zealand Separation
Australia-Antarctica Separation
Zeland Drowing
Wallacea
African Mid-Continental Sea
Entire Africa
Africa collided with Eurasia.
GAAR
Andean uplift
SouthAmerica-Antarctica Separation
Panama
Northern H.
Southern H.
100
90
80
70
60
50
40
30
20
10
0
Time (Million Years Ago)
Dispersal biotic events (Van der Made 1999; Martínez-Navarro 2010; Sen 2013)
Embrithopoda event
Brachyodus event
Gomphotherium Landbridge
Anchitherium event
Conohyus/Pliopithecus event
Tethytragus event
Hipparion event
Gazella event
Pachycrocuta event
Elephant/ Equus event
Geological conventions
Periods with intensified uplift
Orogenic processes and conection
Sea level fluctiations processes
Tectonic processes
Landbridge between continents or fluctuating conections.
Glacial processes

Conversely, the colonization of freshwater environments in North America from marine habitats was promoted probably by the important abundance of these marine lineages (Bell and Everhart 2009; Wilson et al. 2011), due to their presence would implied a possible ecological competence (Rees and Lindgren 2005). Likewise, the freshwater habitats would represent a novel source of adaptive zones and their aquatic morphological traits inhered from their marine ancestors, might constitute preadaptations to subsequent diversification in rivers and lakes (Gould and Vrba 1982). The patterns also suggest substantial differences between the diversification time of Suliformes and Pelecaniformes. This might suggest that Pelecaniformes evolution, which was restricted initially to North America, was affected by the prominent environmental changes around the K/T (Longrich et al. 2011). The colonization of some Asian areas for stem Pelecaniformes made possible that many lineages were able to survive in refugia zones. Subsequently, along the Eocene, the Indian collision with Asia generated the beginning of a continuous process of diverse climatic and geological changes (Chatterjee et al. 2013), which configures new riverine habitats for diversification of early pelecaniform-like lineages. These patterns are consistent with the high richness for freshwater birds in Asia (Buckton and Ormerod 2002), the presence of basal herons (Ardeidae) in Asia (Elzanowski and Zelenkov 2015) as well as the radiation of other bird groups associated with riverine environments such as chats (Turdidae) during the Eocene (Landmann and Winding 1993) and the evolution of ibisbill (Ibidorhynchidae) confined in Asia (Knystautas et al. 1996). Finally, during the Eocene and Oligocene diverse colonization events towards Europe and Africa allowed the differentiation and evolution of Pelecaniformes families, with clades such as Pelecanidae reaching a broad distribution (Louchart et al. 2010; Stidham et al. 2014a) meanwhile others such as Balaenicipitidae and Scopidae remain in Africa (Mayr 2003a).

3.5.8. Afroaves historical biogeography

The paleobiogeographical model obtained proposes a Gondwanan origin for the evolution of Telluraves (Fig.1B). Along the late upper Cretaceous, Telluraves ancestors would have dispersed from South America and Antarctica to Africa and Australia. Likewise, around 66 Ma Australaves and Afroaves diverged each other. Our findings are partially consistent with the "Gondwana break up model", which explains the evolutionary processes of early bird lineages by isolation between Africa, and South America, Antarctica and Australia (Cracraft 2001; Ericson 2012). However, our

approach proposes a colonization of Europe from Africa by Afroaves before the K/T event with successive faunal interchange events between these continents during the Paleocene and Eocene. These processes would have been facilitated by the relative closeness between Old World continents (Gheerbrant and Rage 2006; Ezcurra and Agnolin 2012) and the warm climates of Europe during these epochs (Lindow and Dyke 2006; Collinson and Hooker 2003). Europe constituted an archipelago (Rögl 1999) with tropical conditions and island environments that might allow allopatric processes promoting evolutionary radiation (Andersen et al. 2014). Additionally, these environmental features would have conditioned a great diversity of food resources (Collinson and Hooker 2003; Whitfield and Kjer 2008; Condamine et al. 2013). These conditions would have promoted the observed great diversification of European bird lineages. Likewise, these patterns are in line with the European diversification of Caprimulgiformes families, previously commented (Mayr 2003b; Mayr 2005a; Mayr 2009; Mayr 2010).

Considering the African scenario, the development of early Accipitriformes ancestors during the Paleocene might be related to the absence of modern carnivore mammal lineages, which were mainly concentrated in North America and Eurasia (van der Made 1999), as well as the progressive loss of African carnivore lineages such as creodonts and nimravids (van Valkenburgh 1999). In Africa, small-size mammals probably constituted important resources of prey for raptor ancestors (Mayr 2009). Meanwhile, the ancestors of New World vultures would have evolved in Europe with a further colonization of America (Tambussi and Degrange 2013); their extinction in Old World environments might be connected to the development of scavenging habits by some lineages of Accipitridae (Aegypiinae), which diversified during the Miocene as result of growing abundance of herbivore mammals (Zhang et al. 2010). Strigiformes evolved in Europe and colonized North America and Africa in the late Paleocene and early Eocene respectively. Their nocturnal habits would be connected with the abundance of small nocturnal mammals during the Paleocene and the prominent presence of Carnivore mammals in Northern Hemisphere (Mayr 2009). However, also is possible that owls specialized in nocturnal preys due to the competition with the emerging diurnal raptors (Mayr 2009), which colonized Europe and dispersed worldwide during the Oligocene and Miocene, coinciding with the diversification of many rodents and lagomorph groups (van der Made 1999; Dawson 2003; Heissig 2003; Fejfar et al. 2011; Álvarez-Sierra et al. 2013; López-Guerrero et al. 2015).

Around the Paleocene-Eocene thermal Maximum, which established generalised warm and tropical conditions with temperate forest at highest latitudes (Smith et al. 2006; Röhl et al. 2007; Zachos et al. 2008), diverse interchange events in insectivorous and frugivorous lineages were registered. The presence of land bridges with tropical conditions between Europe and North America (i.e The Geer or Thulean route) favoured fauna interchanges (Sanmartín et al. 2001; Brikiatis 2014). Diverse groups such as Leptosomiformes, Coliiformes and Coraciformes dispersed from Europe to North America (Clarke et al. 2009; Ksepka and Clarke 2010b; Ksepka and Clarke 2010c). Meanwhile, Trogoniformes colonized Africa. During the Oligocene other lineages colonized Africa, Asia and North America, in relation to different geobiological events at the Eocene – Oligocene transition such as the Great Coupure and global cooling (Mayr 2011c).

The broad distribution of Afroaves suggested by our results in Northern Hemisphere environments during the Paleogene suffered an important change during the Miocene that produce the nowadays-biogeographical pattern. The emergence of a highly seasonal global climate regime during the late Miocene limited the food sources along the colder periods in winter. These processes would cause the extinction in northern latitudes of predominantly frugivorous and insectivorous birds such as Coliiformes, or some Piciformes and Coraciformes lineages (Mayr 2011c). Due to these birds probably tended to conserve a relatively narrow physiological thermal tolerance inhered from their tropical ancestors (Ghalambor et al. 2006). According with this, many of these families retracted their distribution towards tropical biomes in equatorial latitudes of the Old and New World (Del Hoyo and Collar 2014).

3.5.9. Australaves historical biogeography

Our findings proposed a scenario in which Australaves ancestor achieved a broad geographic distribution across the southern continents of Gondwana around the Cretaceous-Paleogene boundary (Fig.1B), this implies the divergence from Afroaves through a vicariance process (Ericson 2012) and, therefore, a scenario of convergent evolution of Australaves and Afroaves lineages in diverse ecological niches is reasonable. Predator birds such as Cariamiformes and Falconiformes in South America and Antarctica or Accipitriformes and Strigiformes in Africa and Europe filled faunivorous adaptive zones. Moreover, in Australia took place the evolution of early

Psittaciformes and Passeriformes, with similar ecological adaptations respect to Afroeuropean lineages such as Trogoniformes, Coraciformes or Piciformes (Ericson 2012).

During the late Paleocene and Early Eocene the gradual process of separation of Southernmost continents of Gondwana (Sanmartín and Ronquist 2004) promoted the diversification in Australaves. Moreover, the global warming conditions caused that tropical forest extended 10-15 degrees polewards (Jaramillo et al. 2006; Jaramillo et al. 2010), and Antarctica was covered by temperate forests (Poole and Cantrill 2006). This latitudinal climatic gradient conditioned the biomes structure allowing the isolation of some lineages in South America respect to Antarctica and Australia due to ecological specialization in tropical moist and dry forests (Hernández Fernández and Vrba 2005). However land bridges persisted between landmasses, which enabled subsequent dispersal processes in lineages probably more generalist, such as faunivorous Phorusrhacids and basal Falconids, recorded in Antarctica during the Eocene (Tambussi and Degrange 2013). During the early Paleogene, mammal faunas from South America, Australia and Antarctica were dominated by diverse small body-size lineages of marsupials or animals such as the extinct gondwanaterians (Reguero et al. 2002; Chimento et al. 2015). Conversely, other mammals such astrapoterians and notoungulates achieved larger sizes (Reguero et al. 2002; Ortiz-Jaureguizar and Cladera 2006). These mammal assemblages were mainly herbivorous and omnivorous taxa. The carnivorous mammal lineages, highly developed in Northern Hemisphere (van Valkenburgh 1999), were represented only by the sparassodontians in South American ecosystems with a relative low diversity (Prevosti et al. 2013). On the other hand in Australia, the emergency of marsupial carnivorous lineages was during the Oligocene (Glen and Dickman 2014). Under this ecological scenario, the prominent absence of carnivorous mammal species probably was an important factor that promoted the evolution of predator Australaves lineages.

In South America the Cariamiformes lineages would had a broad ecological success as well as developed a diversity of sizes (Alvarenga and Höfling 2003), which allow them occupy niches as dominant terrestrial hunters in relation with medium and big-size herbivorous preys (Tambussi and Degrange 2013). The similarities between of small forms (Cariamidae) with African secretarybirds (Sagiitaridae) support the process of convergence commented before (Ericson 2012). Likewise, during their evolutionary

history diverse linages of Cariamiformes colonized Europe through Africa during the middle Eocene (Angst et al. 2013). This is consistent with the presence of "stepping stones" or the establishment of land bridges by sea level fluctuations, which allowed novel colonization events for land animals as reported for mammal groups (Poux et al. 2006; de Oliveira et al. 2009).

Falconiformes diversified from South America and Antarctica during the Eocene as evidenced by the oldest fossil record for falcon-like species in Antarctica and South America (Tambussi and Degrange 2013), as well as the prominent presence and ecological diversity of basal lineages in Neotropical environments (Fuchs et al. 2011; Fuchs et al. 2012). Probably falcons would have colonized other continents from South America through Africa during the late Oligocene, with a subsequent worldwide diversification during the late Miocene and Pliocene represented by *Falco* species, this adaptive radiation was promoted by establishment and extension of open and seasonal environments such as savannas due to global cooling trends (Fuchs et al. 2015) (see more discussion and details in Chapter 3).

The patterns for Psittaciformes suggest an Australian and Zealander origin, these findings are consistent with the fossil evidence of crown Psittaciformes, as well as the extant presence of clades such as Nestorinae and Cacatuinae (Boles 1993; White et al. 2011). However, there was a significant presence of stem Psittaciformes families in the Northern Hemisphere (Waterhouse 2006; Mayr 2009; Ksepka et al. 2011; Ksepka and Clarke 2012). Stem groups such as Messelsasturidae and Halcyornithidae (Ksepka et al. 2011) presented some anatomical features that resemble to Falconiformes and Strigiformes birds, and even initially classified within these clades (Mayr 2014b). According with this, we postulate a scenario for early evolution of Psittaciformes as predator species along their early diversification consistent with the parallel evolution of Falconiformes in South America and Accipitriformes in Africa and probably promoted by the absence of carnivorous mammals in Australia (Glen and Dickman 2014). This is also consistent with the dietary habits of keas and kakas (*Nestor*), the most basal lineage of crown Psittaciformes (Schweizer et al. 2010) with an important component of predatory habits on other birds and mammals (Del Hoyo et al. 1997), which possibly imply some conservancy of ancestral traits. Under this hypothetical scenario, during the late Paleocene Psittaciformes ancestors in Australia evolved a prominent flying capacity associated with the early predator habits. This trait allowed

later expansion towards the North Hemisphere across the tropical environments present during the Late Paleocene and early Eocene (Collinson and Hooker 2003) using routes such as the Kerguelen plateau and India (Chatterjee et al. 2013). This is in line with the presence stem parrot fossils such as *Vastanavis eocaena* (Quercypsittidae) from India (Mayr 2009) or *Namapsitta praeruotorum* in Africa (Mourer-Chauviré et al. 2015). Likewise, diverse factors promoted the subsequent extinction of these lineages during the late Eocene such as the climatic changes that occurred in northern latitudes (Mayr 2011c), as well as the possible ecological competence with other emerging raptor groups (Accipitridae and Strigidae). Despite the extinction of stem lineages, the development of high dispersal capacity of Psittaciformes was inhered by derived lineages in Australia, where developed changes in their dietary regime and were able to disperse subsequently worldwide occupying tropical biomes during the Miocene. This prominent parrots dispersal ability is evidenced in the distribution and diversification of many recent lineages in remote islands such as lorikeet species (*Vini*) (Bellemain and Ricklefs 2008; Del Hoyo and Collar 2014). Therefore, this approach is broadly consistent with the patterns of diversification proposed for crown Psittaciformes clades explained by a pulse model from Australia to the southern continents (Schweizer et al. 2010).

Finally, Passeriformes diverged during the early Eocene boundary in association to the broad extension of tropical environments and the diversification of many insects and plants (Collinson and Hooker 2003; Condamine et al. 2013). The divergence of Zygodactylidae as sister taxa respect to Passeriformes might suggest a similar dispersal event to Northern Hemisphere as in stem Psittaciformes. The diversification of other passeriform clades during the early Eocene was located initially in Australia and Zealand. Acanthisittidae, first evolved in Zealand respect to Suboscines and Oscines, which colonized South American and remained in Australia respectively (Ericson et al. 2002; Ericson 2012).

3.5.10. Paleobiogeographical patterns in Southern and Northern Hemisphere

The high colonization rates towards North America, Europe, Africa and Zealand during the early and middle Upper Cretaceous (Fig. 2, 3A) are related to lineages that came out from South America. The drifting process of Africa respect to South America implied many vicariance and dispersal possibilities, which were favoured by continental

isolation with a relative closeness of landmasses (Gheerbrant and Rage 2006; Ezcurra and Agnolin 2012) and depended specifically of life-history traits such as the flying capacity of each clade. Colonization of Europe is consistent with the existence of land bridges between North America and Europe (Euramerica) that made possible biotic interchange between both continents (Sanmartín et al. 2001). These land bridges would facilitate the entry of terrestrial and flightless birds. Moreover, European colonization events could be also possible through Africa, which is consistent with the biogeographical relationship proposed for both continents during this period (Gheerbrant and Rage 2006; Ezcurra and Agnolin 2012; Novas et al. 2013). North American high colonization rates suggest that during the Upper Cretaceous probably existed different routes of biotic interchange from South America directly or across Africa-Europe. These patterns are consistent with diverse dispersal routes proposed for many dinosaur lineages with Laurasian origin that achieved to colonize South America and Antarctica (Benson et al. 2013; Novas et al. 2013). Finally, the high rates present in Zealand might indicate that an important crossing route towards Zealand was present during the Cretaceous as suggested by Sanmartin and Ronquist (2004).

During the middle Upper Cretaceous the Indian subcontinent, Madagascar and Australia showed an increase of their colonization rates (Fig.2, 3A). This is consistent with the drifting process that these landmasses experimented during the Gondwanan break up, with Madagascar and India diverging around 84 Ma and Australia beginning its separation of West Antarctica during the arise of Tasmanian Sea around 80 Ma (Sanmartín and Ronquist 2004). These processes probably promoted diverse events of vicariance in ancestral lineages and dispersal routes during the early drift process when still persisted a distance that would allow the colonization (Woodburne and Case 1996). Some authors have proposed a dispersal route between these landmasses via the Kerguelen plateau until Eocene times (Noonan and Chippindale 2006b; Chatterjee et al. 2013). Antarctica, South America and Asia presented a relative increase of colonization events around 80 Ma. Asian increases probably have relationship with the isolation that suffered Asiamerica respect to Euramerica during the Turonian sea level increase (Miller et al. 2003). This isolation would extend until the Santonian (Ezcurra and Agnolin 2012). During this period many North American faunal components invaded Asia due to the existence of a broad Bering route, which is consistent with many dinosaur biogeographic patterns (Sereno 1999). The South American and

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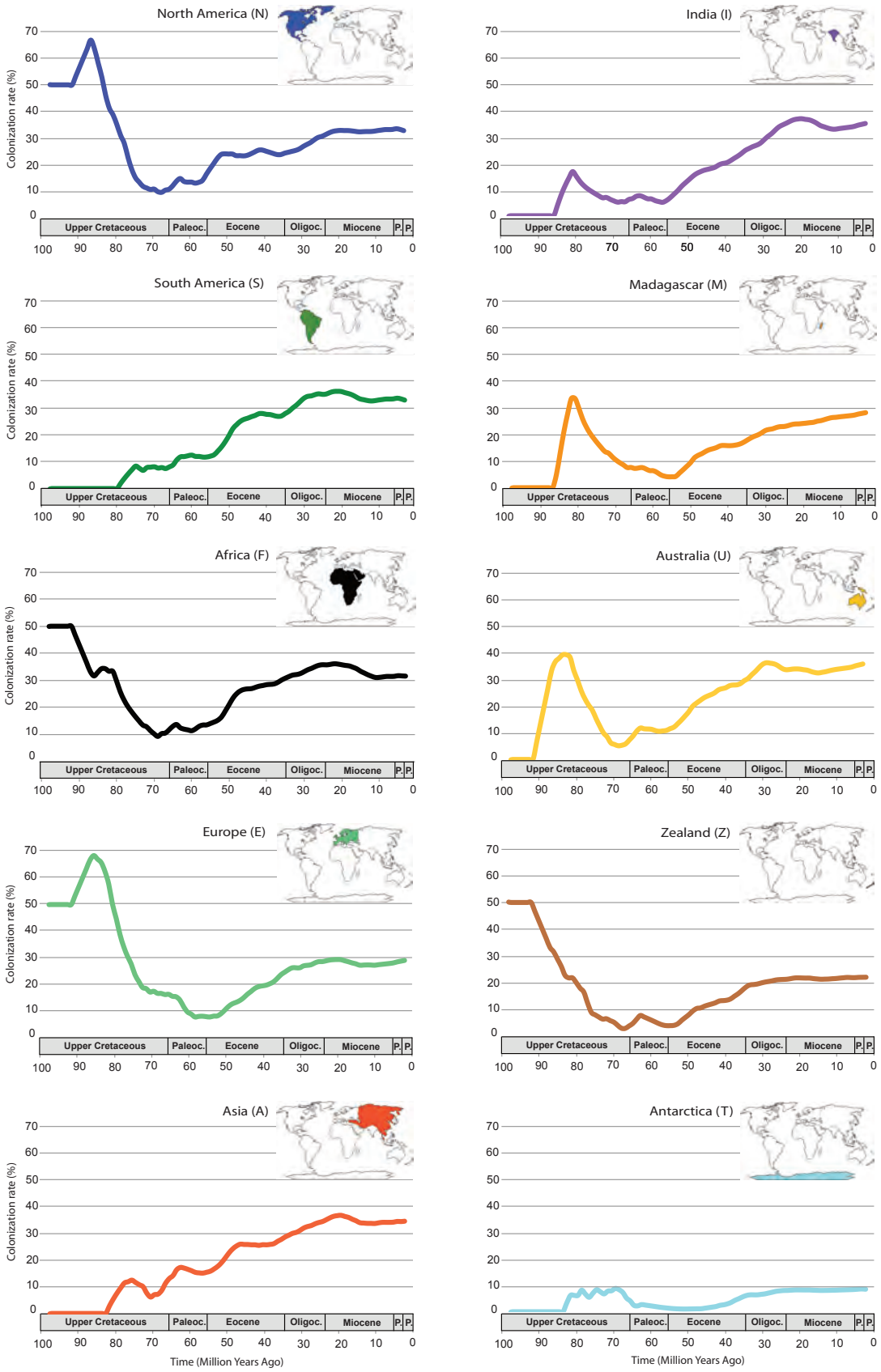

Figure 2. Neornithes colonization rates for in each continent along geologic time.

Antarctica colonizations may suggest an intense dynamics of dispersal events between the Gondwana continents caused by their relative nearness and the establishment of fluctuating land bridges that allowed biotic interchanges and vicariance processes (Sanmartín and Ronquist 2004; Turner 2004; Bocxlaer et al. 2006; Jacobs et al. 2011).

According to our results, around the late Upper Cretaceous all the continents present a substantial decreasing of their colonization rates (Fig. 2, 3A). This is possibly related to the confluence of diverse climate changes, geologic process and astronomical events that triggered the K/T event, in which many biotic groups became extinct (Archibald et al. 2010; Courtillot and Fluteau 2010; Schulte et al. 2010). The pattern obtained points to South America acting as a "cradle" for the early Neornithes birds, and supports the great influence of tectonic and climatic processes in the early evolution of modern birds. This "southern cradle" for Neornithes would implicate an important turnover in global avifaunas during the late Cretaceous and early Paleogene. According to fossil evidence, along theearly and late Cretaceous, the terrestrial-arboreal niches were dominated by Enantiornithes birds (Sanz et al. 1996; Longrich 2009; O'Connor et al. 2011). Conversely, the ornithurine birds were prevalent in aquatic and semiaquatic ecosystems (Longrich 2009), which became abundant with the increase of sea levels during the Turonian (Miller et al. 2003). Enantiornithes bone histology suggest that ontogenic development in these birds was lower than in Ornithurinae (Chinsamy et al. 1995; Chinsamy and Elzanowski 2001). Ornithurine rapid development probably evolved as an adaptive answer to the high predation pressure that probably existed in relation to semiaquatic or ground nesting habits (Lima 2009). These traits and a faster ontogenetic growth probably allowed many ornithurine lineages to survive the late Cretaceous climate crisis, in which changed the plant physiognomy in forest environments where Enanthiornithes lived. Likewise, many habitats in the southernmost latitudes of Gondwana probably acted as refugia for many ornithurine lineages, which remained isolated until they dispersed to lower latitudes during favourable periods (Schulte et al. 2010; Archibald et al. 2010). This evolutionary scenario was initially proposed for invertebrates (Zinsmeister and Feldmann 1984) and later extended to mammals (Reguero et al. 2002; Chimento et al. 2015).

Along the Paleocene and early Eocene our results suggest a generalised increase in colonization rates, which was more significant during the early Eocene (except in

Antarctica) (Fig.2). These results have correspondence with the diversification observed in diverse terrestrial taxa and probably was related with the Paleocene-Eocene thermal maximum (Zachos et al. 2001), which would generate an important expansion of tropical environments polewards and implied the emergency of new niches due to use and availability of diverse food resources (Collinson and Hooker 2003; Jaramillo et al. 2010). Likewise, the presence of land bridges between North America and Europe, allow the colonization of many lineages (Brikiatis 2014), specially forest-dwelling birds (Fig.3A) (Mayr 2009). The novel ecological opportunities made possible the diversification of many frugivorous, insectivorous and even faunivorous taxa (Mayr 2009, 2011c). In this context, a new turnover is consistent with our results; during the early Paleogene Terrestrial, arboreal and actively flying avian lineages (i.e. Telluraves or Caprimulgiformes) occupied the empty terrestrial niches of extinct Enanthiornithes (Mayr 2009).

During the middle and late Eocene, there was a stabilization of colonization rates and a slight decrease around the Eocene-Oligocene boundary (Fig.2). These findings probably have relationship with climatic changes during the last phases of the Terminal Eocene Event 34 Ma (Zachos et al. 2001). Generalised global cooling could facilitate the establishment of a different biome configuration and the subsequent demise of previously widespread groups (Lindow and Dyke 2006). This is also evidenced for insect faunas which constitutes the main nourishment source of many bird species (Toussaint et al. 2012). This cooling trend probably presented major effects in North America, where semiopen deciduous woodlands replaced the ancient evergreen paratropical rainforest (Janis 1993; Fraser and Theodor 2013). These environmental changes affected probably the abundance of forest-arboreal birds from North America respect to Europe where the Tethys Sea acted like as climate moderator (Prothero and Berggren 1994; Akhmetiev et al. 2012). According to this, the European ecosystems would not have achieved the such cooling and drying as in North America (Prothero and Berggren 1994). This is consistent with the extinction of common early Eocene forest-dwelling birds in North America that persisted in Europe (i.e Coliiformes and Coraciformes families) (Mayr 2009; Ksepka and Clarke 2010b; Ksepka and Clarke 2010c).

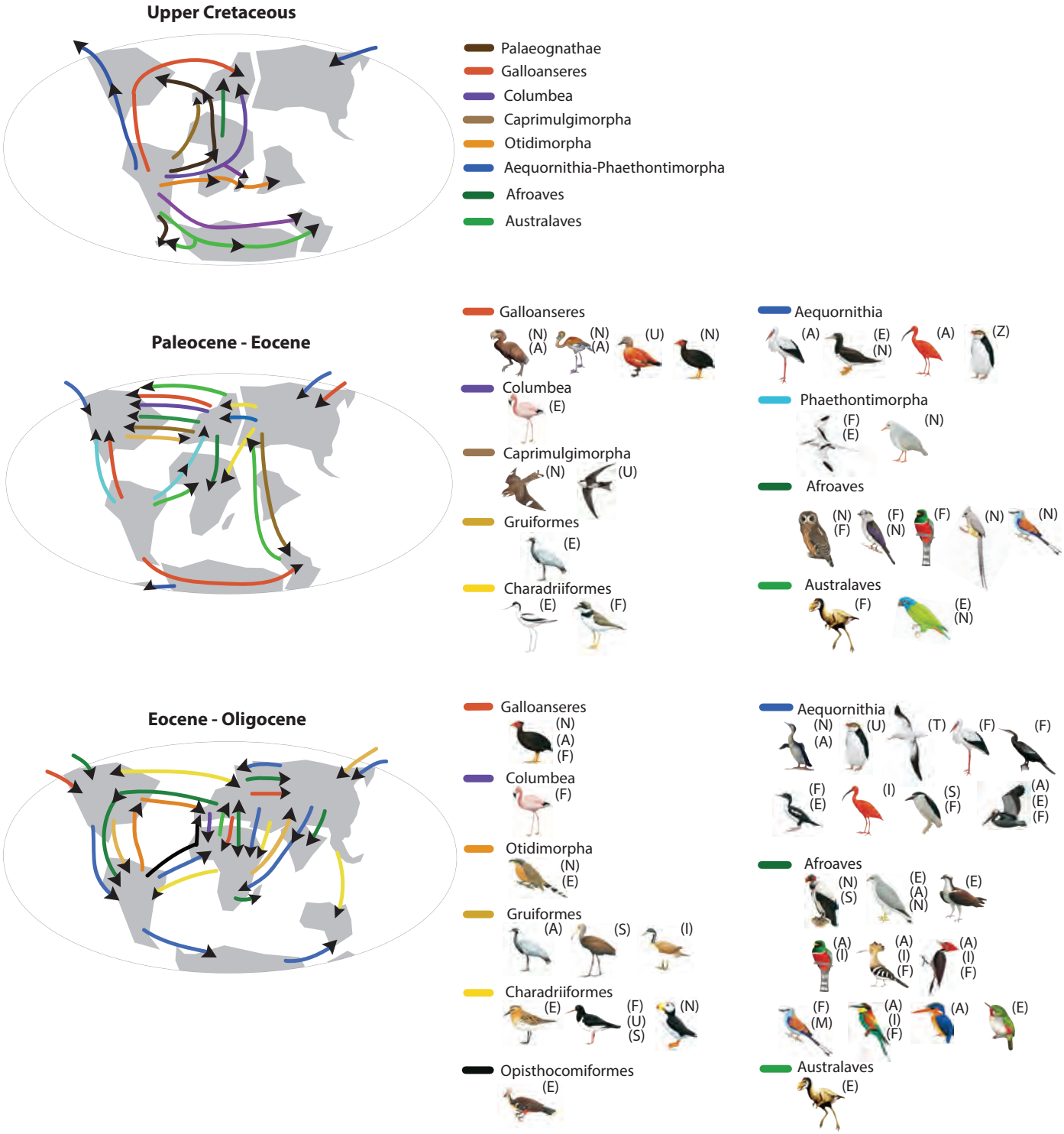

Figure 3A. Summary of paleobiogeographical reconstruction for dispersal main patterns during specific periods since Upper Cretaceous and during Paleogene, which were support by 1-0.5-0.1 Model, the fossil record and extant distribution of species. The bird figures indicate the closest clade implied in colonization event within the high-level clades according with the phylogenetic reconstruction of Figures 1A and 1B.The novel areas colonized are indicated with letter code (A= Asia; E= Europe; F= Africa; I= India; M= Madagascar; N= North America; S= South America; T= Antarctica; U= Australia; Z= Zealand).

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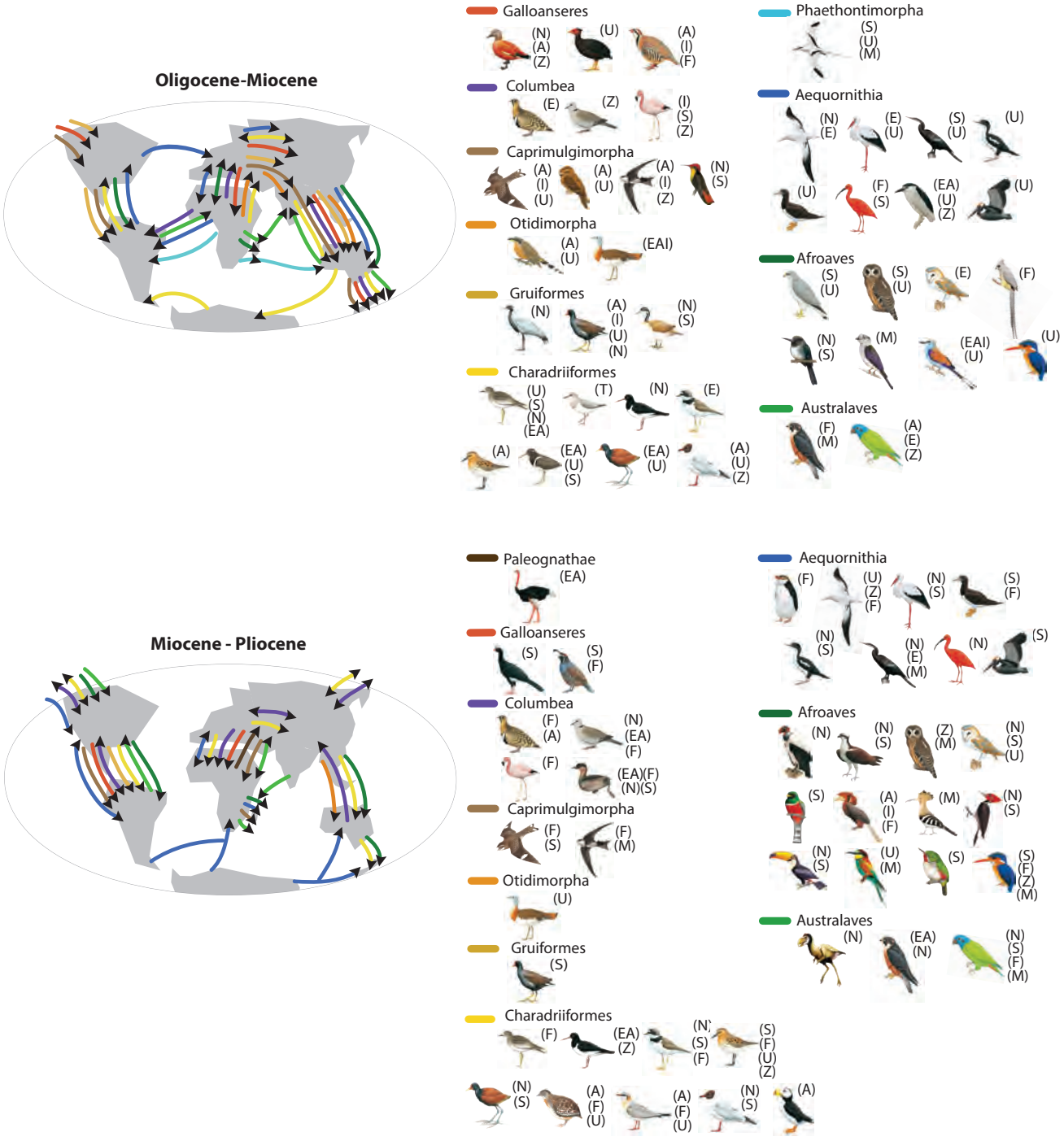

Figure 3B. Summary of paleobiogeographical reconstruction for dispersal main patterns during specific periods of Neogene, which were support by 1-0.5-0.1 Model, the fossil record and extant distribution of species. The bird figures indicate the closest clade implied in colonization event within the high-level clades according with the phylogenetic reconstruction of Figures 1A-B. The novel areas colonized are indicated with letter code (A= Asia; E= Europe; F= Africa; I= India; M= Madagascar; N= North America; S= South America; T= Antarctica; U= Australia; Z= Zealand).

On the other hand, our results suggest that probably diverse lineages dispersed from Europe to Asia (i.e Eogruidae, Protostrigidae, Strigidae, Meropidae, Upupidae and Trogonidae)(Fig.3A-3B). This process is agreement with The Grande Coupure (Stehlin 1909; Costa et al. 2011) studied in mammals faunas, which allowed the direct entry in Europe of diverse Asian lineages (Prothero and Berggren 1994). These interchange probably increased predation ecological interactions causing the extinction of lineages with low flying capacity such galliforms Paraortygidae and Quercymegapodidiae (Mayr 2011c, 2009). The observed tendencies in South America and Antarctica showed an increase of colonization rates during the early Oligocene, this pattern could be related with the cooling process due to the opening of Drake Passage, which generated a new climate regime southwards associated with the circunantarctic ocean currents promoting early icesheets in Antarctica (Francis et al. 2008). The isolation of Antarctica probably promoted the adaptation to cold conditions and allowed the colonization and diversification of diverse lineages of Sphenisciformes and Procellariiformes (Clarke et al. 2007; Ksepka and Clarke 2010a).

The late Oligocene and early Miocene reported the maximum value for colonization rates during the Cenozoic in all continents (Fig.3A-3B). During the Oligocene, the Earth ecosystems experimented important changes through major climate change (Zachos et al. 2001). The cold and arid conditions would facilitate the development of semiopen biomes dominated by C3 grassy species and the evolution of C4 species that spread later across the Late Miocene and Pliocene (Edwards et al. 2010) due to the gradual fragmentation of forest environments restricted to the wet ecotones and the equatorial zones (Woodward et al. 2004). The earlier drier conditions promoted plant adaptations in subtropical forests that allowed a broad expansion during the maximal thermal period between Late Oligocene Warming Event and Miocene Maximun Climate Optimum (Zachos et al. 2001). Under this ecological context, many new lineages adapted to seasonal and dry conditions were able to spread across the continents (Mayr 2011c). Moreover, important crossing routes were established between Africa and Eurasia that made possible the biotic interchange between the continents in middle Miocene times (Pickford and Morales 1994; van der Made 1999; Sen 2013). During this period the avifauna in Europe and Africa presented high similarity, many species of African lineages adapted to dry, open and semiopen environments (Otidiformes and Musophagiformes) and even expanded their

distribution toward similar environments in Europe and Asia (Otididae)(Sánchez Marco 1990; Mlíkovský 2002). Likewise, terrestrial lineages such ostriches (Struthionidae) lineage colonized Europe (Mlíkovský 2002; Mayr 2011c) and Asia (Hou et al. 2005) during the Miocene in line with mammals interchanges during the *Tethytragus* or *Gazella* event (van der Made 1999). From Europe, lineages such Bucerotidae colonized Africa and subsequently Asia during the middle and late Miocene. The intense cooling and aridity process during the late Miocene and Pliocene (van Dam 2006) generated the appearance of a marked seasonal regime in the Northern Hemisphere. This scenario probably implied the retraction of geographical distribution for lineages adapted to tropical conditions in the northern latitudes (Mayr 2011c), which remained in the tropical biomes that persisted in Africa as evidenced Coliidae, Indicatoridae, Struthionidae, and Psittacidae. Probably the devolpment of migratory behaviour in lineages such Meropidae, Coraciidae, Otididae and Upupidae allowed them cope these emerging climatic conditions and conserve their broad distribution in the Old World (Rolland et al. 2014; Pelegrin et al. 2015).

In a parallel process respect to Europe and Africa, diverse North American lineages, many of them coming from Asia using the Bering Land Bridge (Sanmartín et al. 2001) (Fig.3A, 3B) (i.e Gruidae and Rallidae), or with African and European origin through the North Atlantic land bridges such as diverse groups of Coraciformes, Alcediniformes y Piciformes (Sanmartín et al. 2001; Tiffney 2008), were adapted to inhabit warm and dry conditions during the early and middle Miocene. Without adaptations to cope winter conditions, these birds would disperse southward to Central America and later entered in South America. The proximity between North America and South America might generate diverse dispersal events for lineages with high-flying capacity until the terrestrial contact during the Miocene-Pliocene (Montes et al. 2015; Hoorn and Flantua 2015) (Fig.3B). This biogeographical frame explains presence and diversification of warm adapted lineages such as Trochilidae (McGuire et al. 2014), Trogonidae (Dacosta and Klicka 2008), Todidae (Overton and Rhoads 2004) and Ramphastidae (Lutz et al. 2013) in Neotropics since late Miocene until Pleistocene.

Our results suggest an intense increase of colonizations in Australia during the Early Miocene (Fig.3B). In this period, Australia collided with Asia and this process triggered the formation of the Wallacea archipelago during middle-late Miocene (Hall 2009). Which would be crucial in different dispersal opportunities between Asia and

Australia. Wallacea would have worked as "stepping stones" promoting a crossing route as well as an important scenario for speciation in the different islands (Condamine et al. 2013; Moyle et al. 2009). Our findings are consistent with models proposed for Megapodiidae biogeography (Harris et al. 2014) and colonization processes reported for mammals (Rowe et al. 2008).

In a broad view, the analysis of biogeographic patterns in both hemispheres suggested a substantial influence of flight capacity developed by early modern bird ancestors (Mayr 2009), which allowed diverse colonizations achieved some of them broad distributions (i.e Cursoriomorphae). Their role is evidenced also in the continuous colonization rates in the India, Zealand or Madagascar, which have been isolated during long periods. Nevertheless, southern hemisphere patterns show that the distributions of many bird taxa are also explained by vicariance events, in line with the Gondwana break up as previously proposed for birds and other animal groups (Cracraft 2001; Ericson et al. 2002; Sanmartín and Ronquist 2004; Bocxlaer et al. 2006; Yoder and Nowak 2006; Noonan and Chippindale 2006a).

3.5.11. Aquatic birds: paleobiogeographic patterns and evolutionary processes

The results suggest that the aquatic lineages that achieved a wide distribution during their early evolution would reach a constant permanency avoiding the extinction (De Queiroz 2005). The colonization of islands, where the predation pressures are lesser, the development of a broad spectrum of diet, as well as the colonial mating strategy and the migratory behaviour are important features that probably contributed to ecological success of many aquatic groups (Jetz et al. 2008; García-Peña et al. 2009; Davies et al. 2010). Likewise, the intense climate changes transformed the sea currents, their productivity, and equally the availability of adaptive zones. These variations would trigger that some clades were able to survive better than others (Walls et al. 2005; Dobrovolski et al. 2012). According to this, the extinction of lineages such Plotopteridae coincident with the Eocene-Oligocene climate transition and the radiation of Pan-alcidae could suggest a scenario of ecological turnover (Dyke et al. 2011; Smith and Clarke 2014). In the same way, the decrease in Phaethontiformes lineages probably had a relationship with the diversification of marine Lari lineages. Also, specialist lineages such Diomedeoididae, Prophaethontidae and Laricolidae restricted to Tethys and Paratheys area (Mlíkovský 2009; Elzanowski et

al. 2012; De Pietri et al. 2011) probably were affected by the environmental changes in these seas during Oligocene and Miocene (Rögl 1999)(Fig. 3A, 3B). Other seabirds would been affected by the evolution of Pinniped mammals during Late Oligocene (Churchill et al. 2015; Kelley and Pyenson 2015), altering the ecological scenario. Conversely, other birds such as Anhingidae would increase their diversity during the middle and late Miocene (Cenizo and Agnolín 2010), probably influenced by the expansion towards tropical conditions during the Mid-Miocene climate optimum (Zachos et al. 2001). Finally, it's difficult to establish whether there is a causal relationship between the diversification of some aquatic lineages and the extinction of others. However our reconstruction may constitute a first approach to propose a general frame for hypothetical phases of turnover in seabird lineages in relation with climate and geological changes, which could to be improved in the future with new fossil findings.

Overall, our study supports that the Africa-Europe connection constitutes an important route of biotic interchange in the avian history, which is consistent with the model proposed by Ezcurra and Agnolin (2012). Along the geological time, diverse abiotic processes altered and transform the ecosystems worldwide. According to this, our findings propose an outstanding connection between these processes and the colonization patterns in diverse bird clades, which allowed the subsequent diversification and occupancy of novel adaptive zones. In this way, the development of some traits (i.e. diet, physiology, tree-dwelling, migration, etc) enabled certain groups to survive and cope diverse environmental changes. Likewise, many extinction events registered in the avian fossil record showed consistency with our results. Finally, we can conclude that geologic processes and the climate changes have been the main factors affecting deep-time biogeographic patterns in birds.

3.6. ACKNOWLEDGMENTS

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3.7. LITERATURE CITED

Agnolin FL, Novas FE (2012) A carpometacarpus from the upper cretaceous of patagonia sheds light on the Ornithurine bird radiation. *Paläontologische Zeitschrift* 86 (1):85-89

Akhmetiev MA, Zaporozhets NI, Benyamovskiy VN, Aleksandrova GN, Iakovleva AI, Oreshkina TV (2012) The Paleogene history of the Western Siberian seaway: a connection of the Peri-Tethys to the Arctic ocean. *Austrian Journal of Earth Sciences* 105 (1):50-67

Alerstam T, Hedenström A, Åkesson S (2003) Long-distance migration: evolution and determinants. *Oikos* 103 (2):247-260

Alvarenga H (1999) A fossil screamer (Anseriformes: Anhimidae) from the middle Tertiary of southeastern Brazil. . In: Olson SL (ed) Avian paleontology at the close of the 20th century. Proceedings of the 4th international meeting of the Society of Avian Paleontology and Evolution., vol 89. *Smithson Contrib Paleobiol* Washington D.C., pp 223-230

Alvarenga HMF, Höfling E (2003) Systematic revision of the Phorusrhacidae (Aves: Ralliformes). *Papéis Avulsos de Zoologia* 42 (4):55-91

Álvarez-Sierra MÁ, García-Paredes I, Hernández-Ballarín V, Hoek Ostende LWvd, Hordijk K, López-Guerrero P, Meulen AJvd, Oliver A, Peláez-Campomanes P (2013) Models of historical biogeography and continental biochronology. *Spanish Journal of Palaeontology* 28 (2):129-138

Andersen MJ, Naikatini A, Moyle RG (2014) A molecular phylogeny of Pacific honeyeaters (Aves: Meliphagidae) reveals extensive paraphyly and an isolated Polynesian radiation. *Mol Phylogenet Evol* 71:308-315

Angst D, Buffetaut E, Lécuyer C, Amiot R (2013) "Terror Birds"(Phorusrhacidae) from the Eocene of Europe Imply Trans-Tethys Dispersal. *PLoS ONE* 8(11):e80357.

Angst D, Lécuyer C, Amiot R, Buffetaut E, Fourel F, Martineau F, Legendre S, Abourachid A, Herrel A (2014) Isotopic and anatomical evidence of an herbivorous diet in the Early Tertiary giant bird Gastornis. Implications for the structure of Paleocene terrestrial ecosystems. *Naturwissenschaften* 101 (4):313-322.

Archibald JD, Clemens W, Padian K, Rowe T, Macleod N, Barrett PM, Gale A, Holroyd P, Sues H-D, Arens NC (2010) Cretaceous extinctions: multiple causes. *Science* (New York, NY) 328 (5981):973; author reply 975

Baird RF, Vickers-Rich P (1997) *Eutreptodactylus itaboraiensis* gen. et sp. nov., an early cuckoo (Aves: Cuculidae) from the Late Paleocene of Brazil. *Alcheringa* 21 (2):123-127

Baker AJ, Haddrath O, McPherson JD, Cloutier A (2014) Genomic Support for a Moa-Tinamou Clade and Adaptive Morphological Convergence in Flightless Ratites. *Mol Biol Evol*. *31*(7), 1686-1696

Barker FK, Cibois A, Schikler P, Feinstein J, Cracraft J (2004) Phylogeny and diversification of the largest avian radiation. *Proc Natl Acad Sci USA* 101:11040-11045

Barrowclough GF, Groth JG, Mertz LA (2006) The RAG-1 exon in the avian order Caprimulgiformes: phylogeny, heterozygosity, and base composition. *Mol Phylogenet Evol* 41 (1):238-248

Bell A, Everhart MJ (2009) A new specimen of *Parahesperornis* (Aves: Hesperornithiformes) from the Smoky Hill Chalk (Early Campanian) of western Kansas. *Trans Kans Acad Sci* 112 (1/2):7-14

Bellemain E, Ricklefs RE (2008) Are islands the end of the colonization road? *Trends Ecol Evol* 23 (8):461-468

Benson RB, Mannion PD, Butler RJ, Upchurch P, Goswami A, Evans SE (2013) Cretaceous tetrapod fossil record sampling and faunal turnover: implications for biogeography and the rise of modern clades. *Palaeogeogr Palaeoclimatol Palaeoecol* 372:88-107

Benson RBJ, Campione NE, Carrano MT, Mannion PD, Sullivan C, Upchurch P, Evans DC (2014) Rates of dinosaur body mass evolution indicate 170 million years of sustained ecological innovation on the avian stem lineage. *PLoS biol* 12 (5):e1001853

Berthold P (1999) A comprehensive theory for the evolution, control and adaptability of avian migration. *Ostrich* 70 (1):1-11

Blackburn TM, Cassey P, Duncan RP, Evans KL, Gaston KJ (2004) Avian extinction and mammalian introductions on oceanic islands. *Science* 305 (5692):1955-1958

Bocxlaer IV, Roelants K, Biju SD, Nagaraju J, Bossuyt F (2006) Late Cretaceous vicariance in Gondwanan Amphibians. *PLoS ONE* 1 (1):74

Boles WE (1993) A new cockatoo (Psittaciformes: Cacatuidae) from the tertiary of Riversleigh, northwestern Queensland, and an evaluation of rostral characters in the systematics of parrots. *Ibis* 135:8-18

Bond M, Tejedor MF, Campbell Jr KE, Chornogubsky L, Novo N, Goin F (2015) Eocene primates of South America and the African origins of New World monkeys. *Nature* 520 (7548):538-541

Bourdon E, Amaghzaz M, Bouya B (2008) A new seabird (Aves, cf. Phaethontidae) from the Lower Eocene phosphates of Morocco. *Geobios* 41:455-459

Bourdon E, Bouya B, Iarochene M (2005) Earliest African neornithine bird: A new species of Prophaethontidae (Aves) from the Paleocene of Morocco. *J Vertebr Paleontol* 25:157-170

Braun MJ, Huddleston CJ (2009) A molecular phylogenetic survey of caprimulgiform nightbirds illustrates the utility of non-coding sequences. *Mol Phylogenet Evol* 53:948-960

Brikiatis L (2014) The De Geer, Thulean and Beringia routes: key concepts for understanding early Cenozoic biogeography. *J Biogeogr* 1:1-19

Buckton ST, Ormerod SJ (2002) Global patterns of diversity among the specialist birds of riverine landscapes. *Freshw Biol* 47:695-709

Cenizo MM, Agnolín FL (2010) The southernmost records of Anhingidae and a new basal species of Anatidae (Aves) from the lower–middle Miocene of Patagonia, Argentina. *Alcheringa* 34 (4):493-514

Chatterjee S, Goswami A, Scotese CR (2013) The longest voyage: Tectonic, magmatic, and paleoclimatic evolution of the Indian plate during its northward flight from Gondwana to Asia. *Gondwana Res* 23:238-267

Chiappe LM, Dyke GJ (2002) The Mesozoic radiation of birds. *Annu Rev Ecol Syst*:91-124

Chiappe LM, Dyke GJ (2006) The early evolutionary history of birds. *J Paleontol South Korea* 22 (1):133-151

Chiappe LM, Witmer LM (2002) *Mesozoic birds: above the heads of dinosaurs*. University of California Press, Berkeley

Chimento NR, Agnolin FL, Novas FE (2015) The bizarre 'metatherians' *Groeberia* and *Patagonia*, late surviving members of gondwanatherian mammals. *Hist Biol* 27 (5):603-623

Chinsamy A, Chiappe LM, Dodson P (1995) Mesozoic avian bone microstructure: physiological implications. *Paleobiology*:561-574

Chinsamy A, Elzanowski A (2001) Bone histology: evolution of growth pattern in birds. *Nature* 412 (6845):402-403

Chown SL, Gaston KJ, Williams PH (1998) Global patterns in species richness of pelagic seabirds: the Procellariiformes. *Ecography* 21:342-350

Churchill M, Clementz MT, Kohno N (2015) Cope's rule and the evolution of body size in Pinnipedimorpha (Mammalia: Carnivora). *Evolution* 69 (1):201-215

Cibois A, Thibault J-C, Bonillo C, Filardi CE, Watling D, Pasquet E (2014) Phylogeny and biogeography of the fruit doves (Aves: Columbidae). *Mol Phylogenet Evol* 70: 442-453

Claramunt S, Derryberry EP, Remsen JV, Brumfield RT (2012) High dispersal ability inhibits speciation in a continental radiation of passerine birds. *Proc R Soc Lond B* 279 (1733):1567-1574

Clarke JA (2004) Morphology, phylogenetic taxonomy, and systematics of *Ichthyornis* and *Apatornis* (Avialae: Ornithurae). *Bull Am Mus Nat Hist*:1-179

Clarke JA, Ksepka D, Smith NA, Norell MA (2009) Combined phylogenetic analysis of a new North American fossil species confirms widespread Eocene distribution for stem rollers (Aves, Coracii). *Zool J Linn Soc* 157:586-611

Clarke JA, Ksepka DT, Stucchi M, Urbina M, Giannini N, Bertelli S, Narváez Y, Boyd CA (2007) Paleogene equatorial penguins challenge the proposed relationship between biogeography, diversity, and Cenozoic climate change. *Proc Natl Acad Sciences USA* 104 (28):11545-11550.

Clarke JA, Norell MA, Dashzeveg D (2005a) New Avian Remains from the Eocene of Mongolia and the Phylogenetic Position of the Eogruidae (Aves, Gruoidea). *Am Mus Novit* 3494:1-17

Clarke JA, Tambussi CP, Noriega JI, Erickson GM, Ketcham RA (2005b) Definitive fossil evidence for the extant avian radiation in the Cretaceous. *Nature* 433:305-308

Cody M (1973) Coexistence, Coevolution and Convergent Evolution in Seabirds Communities. *Ecology* 54:31-44

Collinson ME, Hooker JJ (2003) Paleogene vegetation of Eurasia: framework for mammalian faunas. In: Reumer JWF, Wessels W (eds) *Distribution and migration of Tertiary mammals in Eurasia. Deinsea* 10. Rotterdam, pp 41-83

Condamine FL, Sperling FAH, Kergoat GJ (2013) Global biogeographical pattern of swallowtail diversification demostrates alternative colonization routes in the Northern and Southern hemispheres. *J Biogeogr* 40:9-23

Contreras-Medina R, Luna-Vega I (2012) Phylogenetic Systematics and Biogeography: Using Cladograms in Historical Biogeography Methods. In: Lawrence S (ed) *Global Advances in Biogeography*. InTech, pp 61-70

Cooper A, Penny D (1997) Mass Survival of Birds Across the Cretaceous- Tertiary Boundary: Molecular Evidence. *Science* 275 (5303):1109-1113.

Costa E, Garcés M, Sáez A, Cabrera L, López-Blanco M (2011) The age of the "Grande Coupure" mammal turnover: New constraints from the Eocene–Oligocene record of the Eastern Ebro Basin (NE Spain). *Palaeogeogr Palaeoclimatol Palaeoecol* 301 (1):97-107

Courtillot V, Fluteau F (2010) Cretaceous extinctions: the volcanic hypothesis. *Science* 328 (5981):973-974

Cox CB (2000) Plate tectonics, seaways and climate in the historical biogeography of Mammals. *Mem Inst Oswaldo Cruz, Rio de Janeiro* 95 (4):509-516

Cracraft J (1973) Vertebrate Evolution and Biogeography in the Old World Tropics: Implications of Continental Drift and Palaeoclimatology. In: Tarling DH, Runcorn SK (eds) *Implications of continental drift to the earth sciences*. Academic Press, London, pp 369-389

Cracraft J (1985) Historical Biogeography and Patterns of differentiation within the South American avifauna: Areas of Endemism. American Ornithologist Union, *Ornithology Monografts* 36:49-84

Cracraft J (2001) Avian evolution, Gondwana biogeography and the Cretaceous Tertiary mass extinction event. *Proc R Soc Lond B* 268:459-469

Crowe TM, Bowie RCK, Bloomer P, Mandiwana TG, Hedderson TAJ, Randi E, Pereira SL, Wakeling J (2006) Phylogenetics, biogeography and classification of, and character evolution in, gamebirds (Aves: Galliformes): effects of character exclusion, data partitioning and missing data. *Cladistics* 22 (6):495-532.

Dacosta JM, Klicka J (2008) The Great American Interchange in birds: a phylogenetic perspective with the genus Trogon. *Mol Ecol* 17:1328-1343

Dalby L, McGill BJ, Fox AD, Svenning JC (2014) Seasonality drives global-scale diversity patterns in waterfowl (Anseriformes) via temporal niche exploitation. *Glob Ecol Biogeogr* 23 (5):550-562

Davies RG, Irlich UM, Chown S, Gaston KJ (2010) Ambient, productive and wind energy, and ocean extent predict global species richness of procellariiform seabirds. *Glob Ecol Biogeogr* 19:98-110

Dawson MR (2003) Paleogene vegetation of Eurasia: framework for mammalian faunas. In: Reumer JWF, Wessels W (eds) *Distribution and migration of Tertiary mammals in Eurasia. Deinsea*, 10. Rotterdam, pp 97-126

de Oliveira FB, Molina EC, Marroig G (2009) Paleogeography of the South Atlantic: a route for primates and rodents into the New World? In: *South American primates*. Springer, pp 55-68

De Pietri VL, Costeur L, Güntert M, Mayr G (2011) A revision of the Lari (Aves, Charadriiformes) from the early Miocene of Saint Gérand le Puy (Allier, France). *J Vertebr Paleonto*l 31:812-828

De Queiroz A (2005) The resurrection of oceanic dispersal in historical biogeography. *Trends Ecol Evol* 20:68-73

Del Hoyo J, Collar NJ (2014) *HBW and BirdLife International Ilustrated Checklist of the Birds of the World, vol I: Non-passerines*. Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (1996) *Hoatzin to Auks. Handbook of the Birds of the World, vol 3*. Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (1997) *Sandgrouse to Cuckoos. Handbook of the Birds of the World, vol 4*. Lynx Edicions, Barcelona

Dobrovolski R, Melo A, Cassemiro F, Diniz-Filho J (2012) Climatic history and dispersal ability explain the relative importance of turnover and nestedness components of beta diversity. *Glob Ecol Biogeogr* 21:191 - 197

Dyke GJ, van Tuinen M (2004) The evolutionary radiation of modern birds (Neornithes): reconciling molecules, morphology and the fossil record. *Zool J Linn Soc* 141:153-177

Dyke GJ, Wang X, Habib MB (2011) Fossil plotopterid seabirds from the Eo-Oligocene of the Olympic Peninsula (Washington State, USA): descriptions and functional morphology. *PLoS ONE* 6(10): e25672.

Edwards EJ, Osborne CP, Strömberg CA, Smith SA (2010) The origins of C4 grasslands: integrating evolutionary and ecosystem science. *Science* 328 (5978):587-591

Elzanowski A, Bieńkowska-Wasiluk M, Chodyń R, Bogdanowicz W (2012) Anatomy of the coracoid and diversity of the Procellariiformes (Aves) in the Oligocene of Europe. *Palaeontology* 55 (6):1199-1221

Elzanowski A, Zelenkov NV (2015) A primitive heron (Aves: Ardeidae) from the Miocene of Central Asia. *J Ornithol*:1-10

Eo SH, Bininda-Emonds ORP, Carroll JP (2009) A phylogenetic supertree of the fowls (Galloanserae, Aves). *Zool Scr* 38 (5):465-481

Ericson PGP (2012) Evolution of terrestrial birds in three continents: Biogeography and parallel radiations. *J Biogeogr* 39:813-824

Ericson PGP, Anderson CL, Britton T, Elzanowski A, Johansson US, Källersjö M, Ohlson JI, Parsons TJ, Zuccon D, Mayr G (2006) Diversification of Neoaves: integration of molecular sequence data and fossils. *Biol Lett* 2 (4):543-547. doi:10.1098/rsbl.2006.0523

Ericson PGP, Christidis L, Cooper A, Irestedt M, Jackson J, Johansson U, Norman JA (2002) A Gondwanan origin of passerine birds supported by DNA sequences of the endemic New Zealand wrens. *Proc R Soc Lond B* 269:235-241

Ezcurra MD, Agnolin FL (2012) A new global palaeobiogeographical model for the Late Mesozoic and Early Tertiary. *Syst Biol* 61 (4):553-566

Feduccia A (2003) "Big bang" for tertiary birds? *Trends Ecol Evol* 18 (4):172-176

Fejfar O, Heinrich W-D, Kordos L, Maul L (2011) Microtoid cricetids and the early history of arvicolids (Mammalia, Rodentia). *Palaeontol Electron* 14 (3 27A):1 - 38

Francis J, Marenssi S, Levy R, Hambrey M, Thorn V, Mohr B, Brinkhuis H, Warnaar J, Zachos J, Bohaty S (2008) From greenhouse to icehouse: the Eocene/Oligocene in Antarctica. *Developments in Earth and Environmental Sciences* 8:309-368

Frank-Hoeflich K, Silveira LF, Estudillo-López J, García-Koch AM, Ongay-Larios L, Piñero D (2007) Increased taxon and character sampling reveals novel intergeneric relationships in the Cracidae (Aves: Galliformes). *J Zool Syst Evol Res* 45 (3):242-254

Fraser D, Theodor JM (2013) Ungulate diets reveal patterns of grassland evolution in North America. *Palaeogeogr Palaeoclimatol Palaeoecol* 369:409-421

Fuchs J, Chen S, Johnson JA, Mindell DP (2011) Pliocene diversification within the South American Forest falcons (Falconidae: *Micrastur*). *Mol Phylogenet Evol* 60:398-407

Fuchs J, Johnson JA, Mindell DP (2012) Molecular systematics of the caracaras and allies (Falconidae: Polyborinae) inferred from mitochondrial and nuclear sequence data. *Ibis* 154 (3):520-532

Fuchs J, Johnson JA, Mindell DP (2015) Rapid diversification of falcons (Aves: Falconidae) due to expansion of open habitats in the Late Miocene. *Mol Phylogenet Evol* 82:166-182

García-Peña GE, Thomas GH, Reynolds JD, Székely T (2009) Breeding systems, climate, and the evolution of migration in shorebirds. *Behav Ecol* 20 (5):1026-1033.

Garcia-R JC, Gibb GC, Trewick SA (2014) Eocene diversification of crown group Rails (Aves: Gruiformes: Rallidae). *PLoS ONE* 9 (10):e109635

Ghalambor CK, Huey RB, Martin PR, Tewksbury JJ, Wang G (2006) Are mountain passes higher in the tropics? Janzen's hypothesis revisited. *Integ Comp Biol* 46 (1):5-17

Gheerbrant E, Rage JC (2006) Paleobiogeography of Africa: how distinct from Gondwana and Laurasia? *Palaeogeogr Palaeoclimatol Palaeoecol* 241:224-246

Gill FB (2007) *Ornithology*. 3 edn. WH Freeman, New York

Gillespie R, Baldwin B, Waters J, Fraser C, Nikula R, Roderick G (2011) Long-distance dispersal: a framework for hypothesis testing. *Trends Ecol Evol* 27:47 - 56

Givnish TJ, Renner SS (2004) Tropical intercontinental disjunctions: Gondwana breakup, immigration from the Boreotropics, and transoceanic dispersal. *Int J Plant Sci* 165 (Suppl):S1-S6

Glen A, Dickman C (2014) *Carnivores of Australia: Past, Present and Future*. CSIRO Publishing

Gould SJ, Vrba E (1982) Exaptation: A Missing Term in the Science of Form. *Paleobiology* 8 (1):4-15

Hackett SJ, Kimball RT, Reddy S, Bowie RCK, Braun EL, Braun MJ, Chojnowski JL, Cox WA, Han K-L, Harshman J, Huddleston CJ, Marks BD, Miglia KJ, Moore WS, Sheldon FH, Steadman DW, Witt CC, Yuri T (2008) A Phylogenomic Study of Birds Reveals Their Evolutionary History. *Science* 320 (5884):1763-1768.

Hall R (2009) Southest Asia′s changing palaeogeography. *Blumea* 54:148-161

Harris RB, Birks SM, Leaché AD (2014) Incubator birds: biogeographical origins and evolution of underground nesting in megapodes (Galliformes: Megapodiidae). *J Biogeogr* 41 (11):2045-2056

Hawkins BA, McCain CM, Davies TJ, Buckley LB, Anacker BL, Cornell HV, Damschen EI, Grytnes J-A, Harrison S, Holt RD, Kraft NJB, Stephens PR (2012) Different evolutionary histories underlie congruent species richness gradients of birds and mammals. *J Biogeogr* 39:825-841

Hedenström A (2010) Extreme endurance migration: what is the limit to non-stop flight. *PLoS Biol* 8 (5):e1000362

Heissig K (2003) Origin and early dispersal of the squirrels and their relatives. In: Reumer JWF, Wessels W (eds) *Distribution and migration of Tertiary mammals in Eurasia. Deinsea*, 10. Rotterdam, pp 277-286

Hernández Fernández M, Vrba E (2005) Macroevolutionary processes and biomic specialization: testing the resource-use hypothesis. *Evol Ecol* 19:199-119

Hinsley SA, Ferns PN, Thomas DH, Pinshow B (1993) Black-bellied Sandgrouse (*Pterocles orientalis*) and Pin-tailed Sandgrouse (*Pterocles alchata*): closely related species with differing bioenergetic adaptations to arid zones. *Physiol Zool*:20-42

Holdgate MW (1965) The fauna of the Tristan da Cunha Islands. *Philos Trans R Soc B* 249 (759):361-402

Hoorn C, Flantua S (2015) An early start for the Panama land bridge. *Science* 348 (6231):186-187

Hope S (2002) The Mesozoic radiation of Neornithes. In: Chiappe LM, Witmer LM (eds) *Mesozoic birds: above the heads of dinosaurs.* University of California Press, Berkeley, p 520

Hou L, Zhou Z, Zhang F, Wang Z (2005) A Miocene ostrich fossil from Gansu Province, northwest China. *Chin Sci Bull* 50 (16):1808-1810

Houde PW (1988) Paleognathous birds from the early Tertiary of the Northern Hemisphere. *Publications of the Nuttall Ornithological Club* 22:1-148

Hughes JM (1996) Phylogenetic analysis of the Cuculidae (Aves, Cuculiformes) using behavioral and ecological characters. *The Auk*:10-22

Jacobs BF (2004) Palaeobotanical studies from tropical Africa: relevance to the evolution of forest, woodland and savannah biomes. *Philos Trans R Soc B* 359 (1450):1573-1583

Jacobs LL, Strganac C, Scotese C (2011) Plate motions, Gondwana Dinosaurs, Noah's Arks, beached Viking funeral ships, ghost ships, and Landspans. *An Acad Bras Cienc* 83 (1):3-22

Janis CM (1993) Tertiary Mammal evolution in the context of changing climates, vegetation, and tectonic events. *Annu Rev Ecol Syst* 24:467-500

Jaramillo CA, Ochoa D, Contreras L, Pagani M, Carvajal-Ortiz H, Pratt LM, Krishnan S, Cardona A, Romero M, Quiroz L, Rodríguez G, Rueda MJ, de la Parra F, Morón S, Green W, Bayona G, Montes C, Quintero O, Ramírez R, Mora G, Schouten S, Bermúdez H, Navarrete R, Parra F, Alvarán M, Osorno J, Crowley JL, Valencia V, Vervoort J (2010) Effects of rapid global warming at the Paleocene-Eocene boundary on Neotropical vegetation. *Science* 330:957 - 961

Jaramillo CA, Rueda MJ, Mora G (2006) Cenozoic plant diversity in the Neotropics. *Science* 311:1893-1896

Jarvis ED, Mirarab S, Aberer AJ, Li B, Houde P, Li C, Ho SYW, Faircloth BC, Nabholz B, Howard JT, Suh A, Weber CC, da Fonseca RR, Li J, Zhang F, Li H, Zhou L, Narula N, Liu L, Ganapathy G, Boussau B, Bayzid MS, Zavidovych V, Subramanian S, Gabaldón T, Capella-Gutiérrez S, Huerta-Cepas J, Rekepalli B, Munch K, Schierup M, Lindow B, Warren WC, Ray D, Green RE, Bruford MW, Zhan X, Dixon A, Li S, Li N, Huang Y, Derryberry EP, Bertelsen MF, Sheldon FH, Brumfield RT, Mello CV, Lovell PV, Wirthlin M, Schneider MPC, Prosdocimi F, Samaniego JA, Velazquez AMV, Alfaro-Núñez A, Campos PF, Petersen B, Sicheritz-Ponten T, Pas A, Bailey T, Scofield P, Bunce M, Lambert DM, Zhou Q, Perelman P, Driskell AC, Shapiro B, Xiong Z, Zeng Y, Liu S, Li Z, Liu B, Wu K, Xiao J, Yinqi X, Zheng Q, Zhang Y, Yang H, Wang J, Smeds L, Rheindt FE, Braun M, Fjeldsa J, Orlando L, Barker FK, Jønsson KA, Johnson W, Koepfli K-P, O'Brien S, Haussler D, Ryder OA, Rahbek C, Willerslev E, Graves GR, Glenn TC, McCormack J, Burt D, Ellegren H, Alström P, Edwards SV, Stamatakis A, Mindell DP, Cracraft J, Braun EL, Warnow T, Jun W, Gilbert MTP, Zhang G (2014) Whole-genome analyses resolve early branches in the tree of life of modern birds. *Science* 346 (6215):1320-1331.

Jetz W, Sekercioglu CH, Bohning-Gaese K (2008) The Worldwide Variation in Avian Clutch Size across Species and Space. *PLoS Biology* 6 (12):2650-2657

Jetz W, Thomas HH, Joy JB, Hartman K, Mooers AO (2012) The global diversity of birds in space and time. *Nature* 491 (7424):444-448

Johnson K, Clayton DH (2000a) A molecular phylogeny of the dove genus Zenaida: Mitochondrial and nuclear DNA sequenc. *The Condor* 102 (4):864-870

Johnson K, Clayton DH (2000b) Nuclear and Mitochondrial Genes Contain Similar Phylogenetic Signal for Pigeons and Doves (Aves: Columbiformes). *Mol Phylogenet Evol* 14 (1):141-151

Johnston P (2011) New morphological evidence supports congruent phylogenies and Gondwana vicariance for palaeognathous birds. *Zool J Linn Soc* 163 (3):959-982

Kelley NP, Pyenson ND (2015) Evolutionary innovation and ecology in marine tetrapods from the Triassic to the Anthropocene. *Science* 348 (6232):aaa3716

Knystautas AJ, Hoyo Jd, Elliott A, Sargatal J (1996) Family Ibidorhynchidae (Ibisbill). *Handbook of the birds of the world* 3:326-331

Ksepka D, Clarke JA (2010a) The basal Penguin (Aves: Sphenisciformes) *Perudyptes devriesi* and a phylogenetic evaluation of the Penguin Fossil Record. *Bull Am Mus Nat Hist* 337:1-77

Ksepka D, Clarke JA (2010b) *Primobucco mcgrewi* (Aves: Coracii) from the Eocene Green River Formation: new anatomical data from the earliest constrained record of stem rollers. *J Vertebr Paleontol* 30 (1):215-225

Ksepka DT (2014) Flight performance of the largest volant bird. *Proc Natl Acad Sci USA* Early edition:1-6

Ksepka DT, Bertelli S, Giannini NP (2006) The phylogeny of the living and fossil Sphenisciformes (penguins) *Cladistics* 22:412-441

Ksepka DT, Boyd CA (2012) Quantifying historical trends in the completeness of the fossil record and the contributing factors: an example using Aves. *Paleobiology* 38 (1):112-125

Ksepka DT, Clarke JA (2010c) New fossil mousebird (Aves: Coliiformes) with feather preservation provides insight into the ecological diversity of an Eocene North American avifauna. *Zool J Linn Soc* 160:685-706

Ksepka DT, Clarke JA (2012) A new stem parrot from the Green River Formation and the complex evolution of the grasping foot in Pan-Psittaciformes. *J Vertebr Paleontol* 32 (2):395-406

Ksepka DT, Clarke JA, Grande L (2011) Stem parrots (Aves, Halcyornithidae) from the Green River formation and a combined phylogeny of Pan-Psittaciformes. *J Paleontol* 85 (5):835-852

Ksepka DT, Ware JL, Lamm KS (2014) Flying rocks and flying clocks: disparity in fossil and molecular dates for birds. Proc R Soc Lond B: 281 (1788).

Kurochkin EV, Dyke GJ, Karhu AA (2002) A New Presbyornithid Bird (Aves, Anseriformes) from the Late Cretaceous of Southern Mongolia. *Am Mus Novit* 3866:1-11

Laird MG, Bradshaw JD (2004) The Break-up of a Long-term Relationship: the Cretaceous Separation of New Zealand from Gondwana. *Gondwana Res* 7 (1):273-286

Landmann A, Winding N (1993) Niche segregation in high-altitude Himalayan chats (Aves, Turdidae): does morphology match ecology? *Oecologia* 95 (4):506-519

Larsen C, Speed M, Harvey N, Noyes HA (2007) A molecular phylogeny of the nightjars (Aves: Caprimulgidae) suggests extensive conservation of primitive morphological traits across multiple lineages. *Mol Phylogenet Evol* 42 (3):789-796

Lee MSY, Cau A, Naish D, Dyke GJ (2014) Morphological clock in paleontology, and a Mid-Cretaceous origin of crown Aves. *Syst Biol* 63 (3):442-449

Lima SL (2009) Predators and the breeding bird: behavioral and reproductive flexibility under the risk of predation. *Biol Rev* 84 (3):485-513

Limolino MV, Riddle BR, Whittaker RJ, Brown JH (2010) *Biogeography*. 4 edn. Sinauer Associates, Inc., Sunderlan, MA

Lindow BEK, Dyke GJ (2006) Bird evolution in the Eocene: climate change in Europe and a Danish fossil fauna. *Biol Rev* 81:483-499

Livezey BC (2010) Phylogenetics of modern shorebirds (Charadriiformes) based on phenotypic evidence: analysis and discussion. *Zool J Linn Soc* 160 (3):567-618

Livezey BC, Zusi RL (2007) Higher-order phylogeny of modern birds (Theropoda, Aves: Neornithes) based on comparative anatomy. II. Analysis and discussion. *Zool J Linn Soc* 149:1-95

Longrich N (2009) An ornithurine-dominated avifauna from the Belly River Group (Campanian, Upper Cretaceous) of Alberta, Canada. *Cretac Res* 30 (1):161-177

Longrich NR, Tokaryk T, Field DJ (2011) Mass extinction of birds at the Cretaceous–Paleogene (K–Pg) boundary. *Proc Natl Acad Sci USA* 108 (37):15253-15257

López-Guerrero P, García-Paredes I, Prieto J, López-Antoñanzas R, Álvarez-Sierra MÁ (2015) Palaeodiversity of Cricetodontini during the late Aragonian (middle Miocene) from the European basins. *Palaeobiodivers Palaeoenviron*:1-16

Louchart A, Tourment N, Carrier J (2010) The earliest know pelican reveals 30 million years of evolutionary stasis in beak morphology. *J Ornithol* 152 (1):15-20

Lundberg JG, Sullivan JP, Rodiles-Hernández R, Hendrickson DA (2007) Discovery of African roots for the Mesoamerican Chiapas catfish, Lacantunia enigmatica, requires an ancient intercontinental passage. *Proc Acad Nat Sci Phila* 156 (1):39-53

Lutz HL, Weckstein JD, Patané JSL, Bates JM, Aleixo A (2013) Biogeography and spatio-temporal diversification of Selenidera and Andigena Toucans (Aves: Ramphastidae). *Mol Phylogenet Evol* 69(3):873-883

Martin T (1995) Avian life history evolution in relation to nest sites, nest predation, and food. *Ecol Monogr* 65 (1):101-127

Mayr G (2003a) The phylogenetic affinities of the Shoebill (*Balaeniceps rex*). *J Ornithol* 144:157-175

Mayr G (2003b) Phylogeny of early Tertiary swifts and hummingbirds. *The Auk* 120:145-151

Mayr G (2005a) Fossil hummingbirds in the Old World. *Biologist* 52 (1):12-16

Mayr G (2005b) The Paleogene fossil record of birds in Europe. *Biol Rev* 80:515-542

Mayr G (2009) *Paleogene fossil birds.* Springer, Heilderberg

Mayr G (2010) Phylogenetic relationships of the paraphyletic caprimulgiform birds (nightjars and allies). *J Zool Syst Evol Res* 48 (2):126-137

Mayr G (2011a) Cenozoic mystery birds: on the phylogenetic affinities of bony-toothed birds (Pelagornithidae). *Zool Scr* 40:448-467

Mayr G (2011b) The phylogeny of charadriiform birds (shorebirds and allies): reassessing the conflict between morphology and molecules. *Zool J Linn Soc* 161:916-934

Mayr G (2011c) Two-phase extinction of "Southern Hemispheric" birds in the Cenozoic of Europe and the origin of the Neotropic avifauna. *Palaeobiodivers Palaeoenviron* 91:325-333

Mayr G (2014a) The Eocene *Juncitarsus*: its phylogenetic position and significance for the evolution and higher-level affinities of flamingos and grebes. *Comptes Rendus Palevol* 13:9-18

Mayr G (2014b) The origins of crown group birds: Molecules and Fossils. *Palaeontology* 57 (2):231-241

Mayr G (2015) New remains of the Eocene Prophaethon and the early evolution of tropicbirds (Phaethontiformes). *Ibis* 157 (1):54-67

Mayr G, Alvarenga H, Mourer-Chauviré C (2011) Out of Africa: fossils shed light on the origin of the hoatzin, an iconic Neotropic bird. *Naturwissenschaftlichen* 98:961-966

Mayr G, Micklich N (2010) New specimens of the avian taxa *Eurotrochilus* (Trochilidae) and *Palaeotodus* (Todidae) from the early Oligocene of Germany. *Paläontol Z* 84:387-395

Mayr G, Smith T (2012) A fossil albatross from the Early Oligocene of the North Sea basin. *The Auk* 129 (1):87-95

Mayr G, Zvonok E (2011) Middle Eocene Pelagornithidae and Gaviiformes (Aves) from the Ukrainian Paratethys. *Palaeontology* 54:1347-1359

McDowall RM (2004) What biogeography is: a place for process. *J Biogeogr* 31:345-351

McGuire JA, Witt CC, Remsen JV, Corl A, Rabosky DL, Altshuler DL, Dudley R (2014) Molecular phylogenetics and the diversification of hummingbirds. *Curr Biol* 24 (8):910-916

Meredith RW, Janecka JE, Gatesy J, Ryder OA, Fisher CA, Teeling EC, Goodbla A, Eizirik E, Simão TL, Stadler T, Rabosky DL, Honeycutt RL, Flynn JJ, Ingram CM, Steiner C, Williams TL, Robinson TJ, Burk-Herrick A, Westerman M, Ayoub NA, Springer MS, Murphy WJ (2011) Impacts of the Cretaceous Terrestrial Revolution and KPg Extinction on Mammal Diversification. *Science* 334:521-524.

Miller KG, Sugarman PJ, Browning JV, Kominz MA, Hernández JC, Olsson RK, Wright JD, Feigenson MD, Van Sickel W (2003) Late Cretaceous chronology of large, rapid sea-level changes: Glacioeustasy during the greenhouse world. *Geology* 31 (7):585-588

Mitchell JS, Makovicky PJ (2014) Low ecological disparity in early Cretaceous birds. *Proc R Soc Lond B* 281:20140608

Mlíkovský Jí (2002) *Cenozoic Birds of the World*, vol Part 1: Europe. Praha: Ninox press,

Mlíkovský Jí (2009) Evolution of the Cenozoic marine avifaunas of Europe. *Ann Naturhist Mus Wien* 111A:357-374

Montes C, Cardona A, Jaramillo CA, Pardo A, Silva J, Valencia V, Ayala C, Pérez-Angel L, Rodríguez-Parra L, Ramírez V (2015) Middle Miocene closure of the Central American Seaway. *Science* 348 (6231):226-229

Mourer-Chauviré C, Pickford M, Senut B (2011) The first Palaeogene galliform from Africa. *J Ornithol* 152:617-622

Mourer-Chauviré C, Pickford M, Senut B (2015) Stem group galliform and stem group psittaciform birds (Aves, Galliformes, Paraortygidae, and Psittaciformes, family incertae sedis) from the Middle Eocene of Namibia. *J Ornithol* 156 (1):275-286

Moyle RG, Filardi CE, Smith CE, Diamond J (2009) Explosive Pleistocene diversification and hemispheric expansion of a "great speciator". *Proc Natl Acad Sci USA* 106 (6):1863-1868

Murray PF, Megirian D (1998) The skull of dromornithid birds: Anatomical evidence for their relationship to Anseriformes. *Rec S Austr Mus* 31:51-97

Near TJ, Dornburg A, Eytan RI, Keck BP, Smith WL, Kuhn KL, Moore JA, Price SA, Burbrink FT, Friedman M (2013) Phylogeny and tempo of diversification in the superradiation of spiny-rayed fishes. *Proc Natl Acad Sci USA* 110 (31):12738-12743

Noonan BP, Chippindale PT (2006a) Dispersal and vicariance: The complex evolutionary history of boid snakes. *Mol Phylogenet Evol* 40:347-358

Noonan BP, Chippindale PT (2006b) Vicariant Origin of Malagasy Reptiles Supports Late Cretaceous Antarctic Land Bridge. *Am Nat* 168 (6):730-741

Novas FE, Agnolín FL, Ezcurra MD, Porfiri J, Canale JI (2013) Evolution of the carnivorous dinosaurs during the Cretaceous: the evidence from Patagonia. *Cretac Res* 45:174-215

O'Connor JK, Chiappe LM, Bell A (2011) Pre-modern birds: avian divergences in the Mesozoic. *Living dinosaurs: the evolutionary history of birds*. New Jersey: J Wiley & Sons:39-114

Olson SL, Hasegawa Y (1996) A new genus and two new species of gigantic Plotopteridae from Japan (Aves: Plotopterigidae). *J Vertebr Paleontol* 16:742-751

Ortiz-Jaureguizar E, Cladera GA (2006) Paleoenvironmental evolution of southern South America during the Cenozoic. *J Arid Environ* 66:498-532

Overton LC, Rhoads DD (2004) Molecular phylogenetic relationships based on mitochondrial and nuclear gene sequences for the Todies (*Todus*, Todidae) of the Caribbean. *Mol Phylogenet Evol* 32 (2):524-538

Pacheco MA, Battistuzzi FU, Lentino M, Aguilar RF, Kumar S, Escalante AA (2011) Evolution of Modern Birds revealed by Mitogenomics: Timing the Radiation and Origin of Major Orders. *Mol Biol Evol* 28 (6):1927-1942

Päckert M, Martens J, Wink M, Feigl A, Thomas Tietze D (2012) Molecular phylogeny of Old World swifts (Aves: Apodiformes, Apodidae, *Apus* and *Tachymarptis*) based on mitochondrial and nuclear markers. *Mol Phylogenet Evol* 63:606-616

Paton TA, Baker AJ, Groth JG, Barrowclough GF (2003) RAG-1 sequences resolve phylogenetic relationships within Charadriiform birds. *Mol Phylogenet Evol* 29 (2):268-278

Pelegrin JS, Cantalapiedra JL, Hernández Fernández M (2014) A phylogenetic perspective of the Avian trophic diversification: integrating paleontological and neontological information. 74th *Meeting of the Society of Vertebrate Paleontology conference proceedings*

Pelegrin JS, Cantalapiedra JL, Hernández Fernández M (2015) The macroevolutionary role of migration for bird occupation of biomes with adverse climatic conditions. In: Domingo L, Domingo MS, Fesharaki O et al. (eds) *Current trends in Paleontology and Evolution*. Madrid-Spain., pp 197-199

Pereda-Suberbiola X (2009) Biogeographical affinities of Late Cretaceous continental tetrapods of Europe: a review. *Bulletin de la Société géologique de France* 180 (1):57-71

Phillips MJ, Gibb GC, Crimp EA, Penny D (2009) Tinamous and moa flock together: mitochondrial genome sequence analysis reveals independent losses of flight among ratites. *Syst biol*: doi: 10.1093/sysbio/syp079

Pickford M, Morales J (1994) Biostratigraphy and palaeobiogeography of East Africa and the Iberian Peninsula. *Palaeogeogr Palaeoclimatol Palaeoecol* 112 (3):297-322

Piersma T, Pérez-Tris J, Mouritsen H, Bauchinger U, Bairlein F (2005) Is there a "migratory syndrome" common to all migrant birds? *Ann N Y Acad Sci* 1046 (1):282-293

Poole I, Cantrill DJ (2006) Cretaceous and Cenozoic vegetation of Antarctica integrating the fossil wood record. *Geological Society, London, Special Publications* 258 (1):63-81

Posso SR, Donatelli RJ (2012) Biogeography on the early distribution of cuckoos (Aves: Cuculiformes). *Zoologia (Curitiba)* 29 (3):187-194

Poux C, Chevret P, Huchon D, De Jong WW, Douzery EJ (2006) Arrival and diversification of caviomorph rodents and platyrrhine primates in South America. *Syst Biol* 55 (2):228-244

Prevosti FJ, Forasiepi A, Zimicz N (2013) The evolution of the Cenozoic terrestrial mammalian predator guild in South America: competition or replacement? *J Mamm Evol* 20 (1):3-21

Prothero DR, Berggren WA (1994) *Eocene-Oligocene climatic and biotic evolution*. Princeton University Press,

R Development Core Team (2013) *R: A language and environment for statistical computing*. R Foundation for Statistical Computing. Foundation for Statistical Computing, Vienna, Austria

Rage J-C (1988) Gondwana, Tethys and terrestrial vertebrates during the Mesozoic and de Cainozoic In: Audley-Chalres MG, Hallam A (eds) *Gondwana and Tethys,* vol 37. Geological Society Special Publication, pp 255-273

Ree RH, Smith SA (2008) Maximun likelihood inference of geographic range evolution by dispersal, local extinction and cladogenesis. *Syst Biol* 57 (1):4-14

Rees J, Lindgren J (2005) Aquatic birds from the Upper Cretaceous (Lower Campanian) of Sweden and the biology and distribution of hesperornithiforms. *Palaeontology* 48 (6):1321-1329

Reguero MA, Marenssi SA, Santillana SN (2002) Antarctic Peninsula and South America (Patagonia) Paleogene terrestrial faunas and environments: biogeographic relationships. *Palaeogeogr Palaeoclimatol Palaeoecol* 179 (3):189-210

Ribas CC, Aleixo A, Nogueira ACR, Miyaki CY, Cracraft J (2011) A palaeobiogeographic model for biotic diversification within Amazonia over the past three million years. *Proc R Soc Lond B*:1-9

Ritz MS, Millar C, Miller GD, Phillips RA, Ryan P, Sternkopf V, Liebers-Helbig D, Peter H-U (2008) Phylogeography of the southern skua complex: rapid colonization of the southern hemisphere during a glacial period and reticulate evolution. *Mol Phylogenet Evol* 49 (1):292-303

Rögl F (1999) Mediterranean and Paratethys. Facts and Hypotheses of an Oligocene to Miocene Paleogeography. *Geol Carpathica* 50 (4):339-349

Röhl U, Westerhold T, Bralower TJ, Zachos JC (2007) On the duration of the Paleocene-Eocene thermal maximum (PETM). *Geochemistry, Geophysics, Geosystems* 8 (12)

Rolland J, Jiguet F, Jønsson KA, Condamine FL, Morlon H (2014) Settling down of seasonal migrants promotes bird diversification. *Proc R Soc Lond B*: 281 (1784). doi:10.1098/rspb.2014.0473

Ronquist F (1997) Dispersal-Vicariance analysis: a new approach to the quantification of historical biogeography. *Syst Biol* 46 (1):195-203

Rowe K, Reno M, Richmond D, Adkins R, Steppan S (2008) Pliocene colonization and adaptive radiations in Australia and New Guinea (Sahul): Multilocus systematics of the old endemic rodents (Muroidea: Murinae). *Mol Phylogenet Evol* 47:84 - 101

Sánchez Marco A (1990) A new bustard (Otididae; Aves) from the early Pliocene of Layna (Soria, Spain). *Paleontol i Evol* 23:223-229

Sanmartín I, Enghoff H, Ronquist F (2001) Patterns of animal dispersal, vicariance and diversification in the Holartic. *Biol J Linn Soc* 73:345-390

Sanmartín I, Ronquist F (2004) Southern hemisphere biogeography inferred by event-based models: plant versus animal patterns. *Syst Biol* 53:216-243

Sanz JL, Chiappe LM, Pérez-Moreno BP, Buscalioni AD, Moratalla JJ, Ortega F, Poyato-Ariza FJ (1996) An Early Cretaceous bird from Spain and its implications for the evolution of avian flight. *Nature* 382 (6590):442-444

Schulte P, Alegret L, Arenillas I, Arz JA, Barton PJ, Bown PR, Bralower TJ, Christeson GL, Claeys P, Cockell CS (2010) The Chicxulub asteroid impact and mass extinction at the Cretaceous-Paleogene boundary. *Science* 327 (5970):1214-1218

Schweizer M, Seehausen O, Güntert M, Hertwig ST (2010) The evolutionary diversification of parrots supports a taxon pulse model with multiple trans-oceanic dispersal events and local radiations. *Mol Phylogenet Evol* 54 (3):984-994

Scotese CR (2001) Atlas of Earth history-PALEOMAP project. http://www.scotese.com/. 2014

Scotese CR, Boucot AJ, Mckerrow WS (1999) Gondwanan palaeogeography and palaeoclimatology. *J Afr Earth Sci* 28 (1):99-114

Sen S (2013) Dispersal of African mammals in Eurasia during the Cenozoic: Ways and whys. *Geobios* 46:159-172

Senut B, Pickford M, Ségalen L (2009) Neogene desertification of Africa. *Comptes Rendus Geosci* 341:591-602

Sereno P (1999) The Evolution of Dinosaurs. *Science* 284:2137-2147

Smith NA (2011) Taxonomic revision and phylogenetic analysis of the flightless Mancallinae (Aves, Pan-Alcidae). *ZooKeys* 91:1-116

Smith NA, Clarke JA (2014) Systematics and evolution of the Pan-Alcidae (Aves, Charadriiformes). *J Avian Biol* 46 (2):125-140

Smith T, Rose KD, Gingerich PD (2006) Rapid Asia–Europe–North America geographic dispersal of earliest Eocene primate Teilhardina during the

Paleocene–Eocene thermal maximum. *Proc Natl Acad Sci USA* 103 (30):11223-11227

Springer MS, Meredith RW, Janecka JE, Murphy WJ (2011) The historical biogeography of Mammalia. Philos Trans R Soc Lond B 366 (1577):2478-2502.

Stehlin HG (1909) Remarques sur les faunules de mammifères des couches éocènes et oligocènes du Bassin de Paris. *Société Géologique de France*

Stidham TA, Krishan K, Singh B, Ghosh A, Patnaik R (2014a) A pelican tarsometatarsus (Aves: Pelecanidae) from the latest Pliocene Siwaliks of India. *PLoS ONE* 9(11): e111210.

Stidham TA, Lofgren D, Farke AA, Paik M, Choi R (2014b) A lithornithid (Aves: Palaeognathae) from the Paleocene (Tiffanian) of southern California. *PaleoBios* 31 (1):1-7

Tambussi C, Acosta Hospitaleche C (2007) Antarctic birds (Neornithes) during the Cretaceous-Eocene times. *Rev Asoc Geol Argent* 62 (4):604-617

Tambussi CP, Degrange FJ (2013) *South American and Antarctic Continental Cenozoic Birds: Paleobiogeographic affinities and disparities*. SpringerBriefs in Earth System Sciences. Springer, New York London

Thomassen HA (2005) *Swift as sound. Design and evolution of the echolocation system in Swiftlets (Apodidae: Collocaliini).* Ph.D Thesis. Institute of Biology, Faculty of Mathematics & Natural Sciences, Leiden University,

Thorup K (2006) Does the migration constrain dispersal and range sizes of migratory birds? *J Biogeogr* 33:1166-1171

Tiffney BH (2008) Phylogeography, fossils and northern hemisphere biogeography: the role of physiological uniformitarianism. *Ann Mo Bot Gard* 95 (1):135-143

Toussaint EFA, Condamine FL, Kergoat GJ, Caodevielle-Dulac C, Barbut J, Silvain JF, Le Ru BP (2012) Palaeoenviromental shifts drove the adaptive radiation of a noctuid stemborer tribe (Lepidoptera, Noctuidae, Apameini) in the Miocene. *PLoS ONE* 7(7): e41377

Turner AH (2004) Crocodyliform biogeography during the Cretaceous: evidence of Gondwanan vicariance from biogeographical analysis. *Proc R Soc Lond B* 271 (1552):2003-2009

Turner D (1997) Family Musophagidae (Turacos). *Handbook of the Birds of the World* 4:480-507

van Dam JA (2006) Geographic and temporal patterns in the late Neogene (12–3 Ma) aridification of Europe: the use of small mammals as paleoprecipitation proxies. *Palaeogeogr Palaeoclimatol Palaeoecol* 238 (1):190-218

van der Made J (1999) Intercontinental relatioship Europe- Africa and the Indian Subcontinent. In: Rössner G, Heissig K (eds) *The Miocene Land Mammals of Europe*. Verlag Dr Friedrich Pfeil, München, pp 359-364

van Tuinen M, Butvill DB, Kirsch JA, Hedges SB (2001) Convergence and divergence in the evolution of aquatic birds. *Proc R Soc Lond B* 268 (1474):1345-1350

van Tuinen M, Sibley CG, Hedges SB (1998) Phylogeny and biogeography of Ratite birds inferred from DNA sequences of the mitochondrial ribosomal genes. *Mol Biol Evol* 15 (4):370-376

van Valkenburgh B (1999) Major patterns in the history of carnivorous mammals. *Annu Rev Earth Pl Sc* 27 (1):463-493

Vidal N, Azvolinsky A, Cruaud C, Hedges SB (2008) Origin of tropical American burrowing reptiles by transatlantic rafting. *Biol Lett* 4 (1):115-118

Voelker G (2002) Systematics and historical biogeography of wagtails: Dispersal versus vicariance revisited. *The Condor* 104 (4):725- 739

Walls SS, Kenward RE, Holloway GH (2005) Weather to disperse? Evidence that climatic conditions influence vertebrate dispersal. *J Anim Ecol* 74:190-197

Wang W, Ortiz RDC, Jacques F, Xiang XG, Li HL, Lin L, Li RQ, Liu Y, Soltis PS, Soltis DE (2012) Menispermaceae and the diversification of tropical rainforests near the Cretaceous–Paleogene boundary. *New Phytol* 195 (2):470-478

Warheit KI (1992) A review of the fossil seabirds from the Tertiary of the North Pacific:plate tectonics, paleoceanography, and faunal change. *Paleobiology* 18 (4):401-424

Warren BH, Strasberg D, Bruggemann JH, Prys-Jones R, Thébaud C (2010) Why does the biota of the Madagascar region have such a strong Asiatic flavour? *Cladistics* 26:526-538

Waterhouse DM (2006) Parrots in a nutshell: The fossil record of Psittaciformes (Aves). *Hist Biol* 18 (2):223-234

Wegener A (1912) The Origin of Continents. *Geol Rundsch* 3:276-292

White NE, Phillips MJ, Gilbert MTP, Alfaro-Núñez A, Willerslev E, Mawson PR, Spencer PB, Bunce M (2011) The evolutionary history of cockatoos (Aves: Psittaciformes: Cacatuidae). *Mol Phylogenet Evol* 59 (3):615-622

Whitfield JB, Kjer KM (2008) Ancient rapid radiations of insects: challenges for phylogenetic analysis. *Annu Rev Entomol* 53:449-472

Williams JB, Tieleman BI (2001) Physiological ecology and behavior of desert birds. In: *Current ornithology*. Springer, pp 299-353

Wilson LE, Chin K, Cumbaa S, Dyke G (2011) A high latitude hesperornithiform (Aves) from Devon Island: palaeobiogeography and size distribution of North American hesperornithiforms. *J Syst Palaeontol* 9 (1):9-23

Woodburne MO, Case JA (1996) Dispersal, vicariance, and the late Cretaceous to early Tertiary land mammal biogeography from South America to Australia. *J Mammal* 3 (2):121-161

Woodward F, Lomas M, Kelly C (2004) Global climate and the distribution of plant biomes. *Philos Trans R Soc Lond B* 359 (1450):1465-1476

Worthy AJD, Tennyson C, Jones JA, McNamara JA, Douglas BJ (2007) Miocene waterfowl and other birds from central Otago, New Zealand. *J Syst Palaeontol* 5 (1):1-39

Yoder A, Nowak M (2006) Has Vicariance or Dispersal Been the Predominant Biogeographic Force in Madagascar? Only Time Will Tell. *Ann Rev Ecol Evol Syst* 37:405-431

Yu Y, Harris AJ, Blair C, He X (2015) RASP (Reconstruct Ancestral State in Phylogenies): a tool for historical biogeography. *Mol Phylogenet Evol* 87:46-49

Yu Y, Harris AJ, He XJ (2011) *RASP (reconstruct ancestral state in phylogenies)*. 3.03 edn.,

Zachos J, Pagani M, Sloan L, Thomas E, Billups K (2001) Trends, rhythms, and aberrations in global climate 65 Ma to Present. *Science* 292 (686-693)

Zachos JC, Dickens GR, Zeebe RE (2008) An early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics. *Nature* 451 (7176):279-283

Zhang Z, Zheng X, Zheng G, Hou L (2010) A new Old World vulture (Falconiformes: Accipitridae) from the Miocene of Gansu Province, northwest China. *J Ornithol* 151 (2):401-408

Zhou Z (2004) The origin and early evolution of birds: discoveries, disputes and perspectives from fossil evidence. *Naturwissenschaften* 91:455-471

Zink RM, Blackwell-Rago RC, Ronquist F (2000) The shifting roles of dispersal and vicariance in biogeography. *Proc R Soc Lond B* 267:497-503

Zinsmeister WJ, Feldmann RM (1984) Cenozoic high latitude heterochroneity of Southern Hemisphere marine faunas. *Science* 224 (4646):281-283

3.8. Appendix

Appendix 3.8.1. Table S1. Paleontological and geographical information of extinct families included in phylogenetic tree. **FAD:** FIRST APARITION DATA; **LAD:** LAST APARITION DATA; **Geog. Area:** Geographic Area.
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Clade	Geog. Area	Fossil Age (M.a) FAD	Fossil Age (M.a) LAD	References
Palaeotididae +	(E)	47.80	38.00	(Houde and Haubold 1987; Mlíkovský 2002; Mayr 2009a)
Aepyornithidae +	(F) (M)	0.01	0.01	(Burney et al. 2004; Mayr 2009a)
Dinornithiformes +	(Z)	19.00	16.00	(Worthy et al. 2007; Bunce et al. 2009; Tennyson et al. 2010)
Lithornithidae +	(N) (E)	62.00	47.80	(Houde 1988; Kristoffersen 1999; Leonard et al. 2005; Mayr 2009b, a; Stidham et al. 2014)
Dromornithidae +	(U)	28.10	2.58	(Vickers-Rich 1991; Murray and Megirian 1998; Mayr 2009a; Park and Fitzgerald 2012; Olson 2005)
Gastornithidae +	(N) (E) (A)	59.20	47.80	(Olson 1985; Mlíkovský 2002; Mayr 2005a; Lindow and Dyke 2006; Mayr 2009a; Angst et al. 2014)
Pelagornithidae +	(N) (S) (F) (E) (A) (T)	59.20	2.58	(Bourdon et al. 2010; Mayr and Rubilar-Rogers 2010; Boessenecker and Smit 2011; Mayr and Zvonok 2011; Mayr 2011; Ksepka 2014)
Presbyornithidae +	(N) (S) (A)	72.10	33.90	(Livezey 1997; Ericson 2000; Kurochkin et al. 2002; Lindow and Dyke 2006; Mayr 2009a; Elzanowski and Stidham 2010)
Gallinuloididae +	(N) (E)	56.00	47.80	(Mayr and Weidig 2004; Weidig 2003; Lindow and Dyke 2006; Mayr 2009a, 2014b)
Paraortygidae +	(E)	38.00	23.03	(Mourer-Chauviré 1992; Mayr 2009a; Mourer-Chauviré et al.

				2011)
Quercymegapodiidae +	(N) (S) (E)	69.20	20.44	(Alvarenga 1995; Mlíkovský 2002; Mayr 2009a; Mourer-Chauviré et al. 2011)
Archaeotrogonidae +	(E)	56.00	23.03	(Mlíkovský 2002; Mayr 2005a, 2009a)
Fluvioviridavidae +	(N) (E)	56.00	47.80	(Mayr 2009a; Nesbitt et al. 2011)
Eocypselidae +	(E)	56.00	47.80	(Mayr 2003; Mayr 2009a, 2010, 2014b)
Prophaethontidae +	(N) (F) (E) (A)	66.00	41.30	(Bourdon et al. 2005; Mayr 2005a; Mlíkovský 2002; Mayr 2009a; Mlíkovský 2009)
Palaelodidae +	(N) (S) (E) (F) (U) (Z)	56.00	2.58	(Mlíkovský 2002; Mayr 2004, 2005a, 2009a; Worthy et al. 2010; Mayr 2014a)
Onychopterygidae +	(S)	47.80	41.30	(Cracraft 1971; Mayr 2009a; Tambussi and Degrange 2013)
Eogruidae +	(E) (A)	56.00	3.60	(Cracraft 1969; Clarke et al. 2005; Mayr 2009a, 2014b)
Geranoididae +	(N)	56.00	47.80	(Cracraft 1969; Mayr 2009a)
Messelornithidae +	(N) (E)	66.00	47.80	(Lindow and Dyke 2006; Mayr 2009a; Weidig 2010)
Aptornithidae +	(Z)	20.44	2.58	(Worthy et al. 2007; Worthy et al. 2011)
Plotopteridae +	(N) (A)	38.00	33.90	(Warheit 1992; Olson and Hasegawa 1996; Mayr 2005b, 2009a)
Diomedeoididae +	(E) (A)	33.90	28.10	(Mlíkovský 2002; Mayr 2005a, 2009a; Mlíkovský 2009)
Protoplotidae +	(A)	59.20	47.80	(van Tets et al. 1989; Mayr 2009a)
Laricolidae +	(E)	29.10	28.10	(Mlíkovský 2002; De Pietri et al. 2011; Smith 2015)
Teratornithidae +	(S)	28.10	0.01	(Campbell and Tonni 1980; Olson 1985; Mayr 2009a; Vizcaíno and Fariña 1999; Tambussi and

				Degrange 2013)
Sophiornithidae +	(E) (A)	59.20	23.03	(Mayr 2009a; Kurochkin and Dyke 2012)
Ogygoptyngidae +	(N)	59.20	56.00	(Mayr 2009a; Kurochkin and Dyke 2012)
Protostrigidae +	(N) (E)	56.00	28.10	(Mayr 2009a; Kurochkin and Dyke 2012)
Panleptosomidae +	(N) (E)	56.00	41.30	(Weidig 2006; Mayr 2008, 2009a; Weidig 2010; Mayr 2014b)
Messelirrisoridae +	(E)	56.00	47.80	(Mlíkovský 2002; Mayr 2006, 2009a, 2014b)
Primobucconidae +	(N) (E)	56.00	47.80	(Mayr 2005a; Clarke et al. 2009; Mayr 2009a; Ksepka and Clarke 2010a; Weidig 2010; Mayr 2014b)
Eocoraciidae +	(E)	56.00	47.80	(Mayr and Mourer-Chauviré 2000; Mayr 2005a; Clarke et al. 2009; Mayr 2009a; Ksepka and Clarke 2010a)
Geranopteridae +	(E)	38.00	33.90	(Mayr and Mourer-Chauviré 2000; Mayr 2005a; Clarke et al. 2009; Mayr 2009a)
Sylphornithidae +	(E)	41.30	28.00	(Mlíkovský 2002; Mayr 2005a, 2009a)
Gracilitarsidae +	(E)	47.80	38.00	(Mayr 2001; Mlíkovský 2002; Mayr 2005a, 2009a)
Picavidae +	(E)	33.90	28.10	(Mayr and Gregorová 2012)
Sandcoleidae +	(N) (E)	56.00	41.30	(Mayr 2005a; Lindow and Dyke 2006; Zelenkov and Dyke 2008; Mayr 2009a; Ksepka and Clarke 2010b; Mayr 2014b)
Chascacocoliidae +	(N) (E)	56.00	47.00	(Mayr 2009a, 2013; Zelenkov and Dyke 2008; Ksepka and Clarke 2010b)
Ameginornithidae +	(E) (F)	47.80	33.0	(Peters 2007; Mayr 2009a; Stidham and Smith 2015)
Phorusrhascidae +	(S)(E)(N)	59.20	1.81	(Alvarenga and Höfling 2003; Mayr

				2009a; Tambussi 2011; Tambussi and Degrange 2013)
Idiornithidae +	(E)	47.80	23.03	(Alvarenga and Höfling 2003; Mayr 2005a, 2009a)
Halcyornithidae +	(N) (E)	56.00	47.80	(Mayr 2009a; Ksepka et al. 2011; Ksepka and Clarke 2012; Mayr 2014b)
Quercypsittidae +	(E) (I)	56.00	47.80	(Mayr 2009a; Mayr et al. 2010; Ksepka and Clarke 2012)
Zygodactylidae +	(E)	56.00	23.00	(Mayr 2009a; Weidig 2010; Mayr 2014b)

REFERENCES

Alvarenga HMF (1995) Um Primitivo Membro da Ordem Galliformes (Aves) do Terciário Médio da Bacia de Taubaté, Estado de Sao Paulo, Brasil. *An Acad Bras Cienc* 67:33-44

Alvarenga HMF, Höfling E (2003) Systematic revision of the Phorusrhacidae (Aves: Ralliformes). *Papéis Avulsos de Zoologia* 42 (4):55-91

Angst D, Lécuyer C, Amiot R, Buffetaut E, Fourel F, Martineau F, Legendre S, Abourachid A, Herrel A (2014) Isotopic and anatomical evidence of an herbivorous diet in the Early Tertiary giant bird *Gastornis*. Implications for the structure of Paleocene terrestrial ecosystems. *Naturwissenschaften* 101 (4):313-322. doi:10.1007/s00114-014-1158-2

Boessenecker RW, Smith NA (2011) Latest Pacific basin record of a bony-toothed bird (Aves, Pelagornithidae) from the Pliocene Purisima Formation of California, U.S.A. *J Vertebr Paleontol* 31 (3):652-657

Bourdon E, Amaghzaz M, Bouya B (2010) Pseudotoothed birds (Aves, Odontopterygiformes) from the early Tertiary of Morocco. *Am Mus Novit* 3704:1-71

Bourdon E, Bouya B, Iarochene M (2005) Earliest African neornithine bird: A new species of Prophaethontidae (Aves) from the Paleocene of Morocco. *J Vertebr Paleontol* 25:157-170

Bunce M, Worthy TH, Phillips MJ, Holdaway RN, Willerslev E, Haile J, Shapiro B, Scofield RP, Drummond A, Kamp PJJ, Cooper A (2009) The evolutionary history of the extinct ratite moa and New Zealand Neogene paleogeography. *Proc Natl Acad Sci USA. 106*(49), 20646-20651

Burney DA, Burney LP, Godfrey LR, Jungers WL, Goodman SM, Wright HT, Timothy Jull AJ (2004) A chronology for late prehistoric Madagascar. *J Hum Evol* 47:25-63

Campbell KEJ, Tonni EP (1980) A new genus of teratorn from Huayquerian of Argentina (Aves: Teratornithidae). *Nat Hist Mus Los Angel Cty Sci Ser* 330:59-68

Clarke JA, Ksepka D, Smith NA, Norell MA (2009) Combined phylogenetic analysis of a new North American fossil species confirms widespread Eocene distribution for stem rollers (Aves, Coracii). *Zool J Linn Soc* 157:586-611

Clarke JA, Norell MA, Dashzeveg D (2005) New Avian Remains from the Eocene of Mongolia and the Phylogenetic Position of the Eogruidae (Aves, Gruoidea). *Am Mus Novit* 3494:1-17

Cracraft J (1969) Systematics and Evolution of the Gruiformes (Class, Aves) 1. The Eocene Family Geranoididae and the Early history of the Gruiformes. *Am Mus Novit* 2388:1-40

Cracraft J (1971) A new family of hoatzin-like birds (Order Opisthocomiformes) from the Eocene of South America. *Ibis* 113:229-233

De Pietri VL, Costeur L, Güntert M, Mayr G (2011) A revision of the Lari (Aves, Charadriiformes) from the early Miocene of Saint Gérand le Puy (Allier, France). *J Vertebr Paleontol* 31:812-828

Elzanowski A, Stidham TA (2010) Morphology of the Quadrate in the Eocene Anseriform *Presbyornis* and Extant Galloanserine Birds. *J Morphol* 271:305-323

Ericson PGP (2000) Systematic revision, skeletal anatomy, and paleoecology of the New World early Tertiary Presbyornithidae (Aves: Anseriformes). *PaleoBios* 20:1-23

Houde P, Haubold H (1987) *Palaeotis weigelt*i restudied: A small middle Eocene Ostrich (Aves Struthioniformes). *Palaeovertebrata* 17 (2):27-42

Houde PW (1988) Paleognathous birds from the early Tertiary of the Northern Hemisphere. *Publications of the Nuttall Ornithological Club* 22:1-148

Kristoffersen AV (1999) Lithornithid birds (Aves, Palaeognathae) from the Lower Palaeogene of Denmark. *Geol Mijnb* 78:375-381

Ksepka D, Clarke JA (2010a) *Primobucco mcgrewi* (Aves: Coracii) from the Eocene Green River Formation: new anatomical data from the earliest constrained record of stem rollers. *J Vertebr Paleontol* 30 (1):215-225

Ksepka DT (2014) Flight performance of the largest volant bird. *Proc Natl Acad Sci USA* Early edition:1-6

Ksepka DT, Clarke JA (2010b) New fossil mousebird (Aves: Coliiformes) with feather preservation provides insight into the ecological diversity of an Eocene North American avifauna. *Zool J Linn Soc* 160:685-706

Ksepka DT, Clarke JA (2012) A new stem parrot from the Green River Formation and the complex evolution of the grasping foot in Pan-Psittaciformes. *J Vertebr Paleontol* 32 (2):395-406

Ksepka DT, Clarke JA, Grande L (2011) Stem parrots (Aves, Halcyornithidae) from the Green River formation and a combined phylogeny of Pan-Psittaciformes. *J Paleontol* 85 (5):835-852

Kurochkin EN, Dyke GJ (2012) The First Fossil Owls (Aves: Strigiformes) from the Paleogene of Asia and a Review of the Fossil Record of Strigiformes. *Paleontol J* 45 (4):445-458

Kurochkin EN, Dyke GJ, Karhu AA (2002) A New Presbyornithid Bird (Aves, Anseriformes) from the Late Cretaceous of Southern Mongolia. *Am Mus Novit* 3866:1-11

Leonard L, Van Tuinen M, Dyke GJ (2005) A new specimen of the fossil palaeognath *Lithornis* from the Earliest Palaeogene of Denmark. *Am Mus Novit* 3491:1-11

Lindow BEK, Dyke GJ (2006) Bird evolution in the Eocene: climate change in Europe and a Danish fossil fauna. *Biol Rev* 81:483-499

Livezey BC (1997) A phylogenetic analysis of basal Anseriformes, the fossil Presbyornis and the interordinal relation- ships of waterfowl. *Zool J Linn Soc* 121:361-428

Mayr G (2001) A new specimen of the tiny middle Eocene bird *Gracilitarsus mirabilis* (new family: Gracilitarsidae). *Condor* 103:78-84

Mayr G (2003) Phylogeny of early tertiary swifts and Hummingbirds (Aves: Apodiformes). *The Auk* 120 (1):145-151

Mayr G (2004) Morphological evidence for sister group relationship between flamingos (Aves: Phoenicopteridae) and grebes (Podicipedidae). *Zool J Linn Soc* 140:157-169

Mayr G (2005a) The Paleogene fossil record of birds in Europe. *Biol Rev* 80:515-542

Mayr G (2005b) Tertiary plotopterids (Aves, Plotopteridae) and a novel hypothesis on the phylogenetic relationships of penguins (Spheniscidae). *J Zool Syst Evol Res* 43:61-71

Mayr G (2006) New specimens of the Eocene Messelirrisoridae (Aves: Bucerotes), with comments on the preservation of uropygial gland waxes in fossil birds from Messel and the phylogenetic affinities of Bucerotes. *Palaeontol Z* 80:390-405

Mayr G (2008) The Madagascan "Cuckoo-roller" (Aves: Leptosomidae) is not a roller: notes on the phylogenetic affinities and evolutionary history of a "living fossil". *Acta Ornithol (Wars)* 43 (2):226-230

Mayr G (2009a) *Paleogene fossil birds*. Springer, Heilderberg

Mayr G (2009b) Towards the complete bird: the skull of the Middle Eocene lithornithid (Aves, Lithornithidae). *Bull Inst R Sci Natde Belg* 79:169-173

Mayr G (2010) Reappraisal of *Eocypselus*: a stem group apodiform from the early Eocene of Northern Europe. *Paleobiodivers Palaeoenviron* 90:395-403

Mayr G (2011) Cenozoic mystery birds: on the phylogenetic affinities of bony-toothed birds (Pelagornithidae). *Zool Scr* 40:448-467

Mayr G (2013) Late Oligocene mousebird converges on parrots in skull morphology. *Ibis* 155:384-396

Mayr G (2014a) The Eocene *Juncitarsus*: its phylogenetic position and significance for the evolution and higher-level affinities of flamingos and grebes. *Comptes Rendus Palevol* 13:9-18

Mayr G (2014b) The origins of crown group birds: Molecules and Fossils. *Palaeontology* 57 (2):231-241

Mayr G, Gregorová R (2012) A tiny stem group representative of Pici (Aves, Piciformes) from the early Oligocene of the Czech Republic. *Paläontol Z* 86:333-343

Mayr G, Mourer-Chauviré C (2000) Rollers (Aves: Coraciiformes s.s.) from the Middle Eocene of Messel (Germany) and the Upper Eocene of the Quercy (France). *J Vertebr Paleontol* 20 (3):533-546

Mayr G, Rana RS, Rose KD, Sahni A, Kumar K, Singh L, Smith T (2010) Quercypsitta-like birds from the Early Eocene of India (Aves, ?Psittaciformes). *J Vertebr Paleontol* 30 (2):467-478

Mayr G, Rubilar-Rogers D (2010) Osteology of a new giant bony-toothed bird from the Miocene of Chile, with a revision of the taxonomy of Neogene Pelagornithidae. *J Vertebr Paleontol* 30 (5):1313-1330

Mayr G, Weidig I (2004) The Early Eocene bird *Gallinuloides wyomingensis*: a stem group representative of Galliformes. *Acta Palaeontol Pol* 49 (2):211-217

Mayr G, Zvonok E (2011) Middle Eocene Pelagornithidae and Gaviiformes (Aves) from the Ukrainian Paratethys. *Palaeontology* 54:1347-1359

Mlíkovský Jí (2002) *Cenozoic Birds of the World*, vol Part 1: Europe. Praha: Ninox press,

Mlíkovský Jí (2009) Evolution of the Cenozoic marine avifaunas of Europe. *Ann Naturhist Mus Wien* 111A:357-374

Mourer-Chauviré (1992) The Galliformes (Aves) from the Phosphorites du Quercy (France): systematics and biostratigraphy. In: Campbell KE (ed) *Papers in avian paleontology honoring Pierce Brodkorb*, vol 36. Nat Hist Mus Los Angeles Cty Sci Ser, pp 67-95

Mourer-Chauviré C, Pickford M, Senut B (2011) The first Palaeogene galliform from Africa. *J Ornithol* 152:617-622

Murray PF, Megirian D (1998) The skull of dromornithid birds: Anatomical evidence for their relationship to Anseriformes. *Rec S Austr Mus* 31:51-97

Nesbitt SJ, Ksepka DT, Clarke JA (2011) Podargiform Affinities of the Enigmatic *Fluvioviridavis platyrhamphus* and the Early Diversification of Strisores (''Caprimulgiformes'' + Apodiformes). *PLoS ONE* 6 (11):e26350

Olson SL (1985) The fossil record of birds. In: Farner DS, King JR, Parkes KC (eds) *Avian Biology*, vol 8. Academic Press, NewYork, pp 79-238

Olson SL (2005) Review of Magnificent Mihirungs: the Colossal Flightless Birds of the Australian Dreamtime. *The Auk* 122:367-371

Olson SL, Hasegawa Y (1996) A new genus and two new species of gigantic Plotopteridae from Japan (Aves: Plotopterigidae). *J Vertebr Paleontol* 16:742-751

Park T, Fitzgerald EMG (2012) A late Miocene–early Pliocene Mihirung bird (Aves: Dromornithidae) from Victoria, southeast Australia. *Alcheringa* 36:419-422

Peters DS (2007) The fossil family Ameghinornithidae (Mourer-Chauviré 1981): a short synopsis. *J Ornithol* 148:25-28

Smith NA (2015) Sixteen vetted fossil calibrations for divergence dating of Charadriiformes (Aves, Neognathae). *Palaeontol Electron* 18:1-18

Stidham TA, Lofgren D, Farke AA, Paik M, Choi R (2014) A lithornithid (Aves: Palaeognathae) from the Paleocene (Tiffanian) of southern California. *PaleoBios* 31 (1):1-7

Stidham TA, Smith NA (2015) An ameghinornithid-like bird (Aves, Cariamae,? Ameghinornithidae) from the early Oligocene of Egypt. *Paleontol Electron* 18(1): 1-8

Tambussi CP (2011) Palaeoenvironmental and faunal inferences based on the avian fossil record of Patagonia and Pampa: what works and what does not. *Biol J Linn Soc* 103:458-474

Tambussi CP, Degrange FJ (2013) *South American and Antarctic Continental Cenozoic Birds: Paleobiogeographic affinities and disparities*. SpringerBriefs in Earth System Sciences. Springer, New York London

Tennyson AJD, Worthy TH, Jones CM, Scofield RP, Suzanne JH (2010) Moa's Ark: Miocene Fossils Reveal the Great Antiquity of Moa (Aves: Dinornithiformes) in Zealandia. In: Boles WE, Worthy TH (eds) *Proccedings of the VII international meeting of the Society of Avian Paleontology and Evolution.*, vol 62. Records of the Australian Museum, pp 105-114

van Tets GF, Rich PV, Marino-Hadiwardoyo HR (1989) A reappraisal of *Protoplotus beauforti* from the early Tertiary of Sumatra and the basis of a new pelecaniform family. *Bull Geol Res Dev Cent Paleontol* Ser 5:57-75

Vickers-Rich PV (1991) The Mesozoic and Tertiary history of birds on the Australian plate. In: Vickers-Rich PV, Monaghan TM, Baird RF, Rich TH (eds) *Vertebrate palaeontology of Australasia*. Pioneer Design Studio and Monash University Publications Committee, Melbourne, pp 721-808

Vizcaíno SF, Fariña RA (1999) On the flight capabilities and distribution of the giant Miocene bird *Argentavis rnugnificens* (Teratornithidae). *Lethaia* 32:271-278

Warheit KI (1992) A review of the fossil seabirds from the Tertiary of the North Pacific:plate tectonics, paleoceanography, and faunal change. *Paleobiology* 18 (4):401-424

Weidig I (2003) Fossil birds from the Lower Eocene Green River Formation (USA). Ph.D. Thesis. Johann Wolfgang Goethe Universitat, Frankfurt

Weidig I (2006) The first New World occurrence of the Eocene bird *Plesiocathartes* (Aves: ?Leptosomidae). *Palaöntol Z* 80 (3):230-237

Weidig I (2010) New Birds from the Lower Eocene Green River Formation, North America. *Rec Aust Mus* 62:29-44

Worthy AJD, Tennyson C, Jones JA, McNamara JA, Douglas BJ (2007) Miocene waterfowl and other birds from central Otago, New Zealand. *J Syst Palaeontol* 5 (1):1-39

Worthy TH, Tennyson AJD, Archer M, Scofield RP (2010) First Record of *Palaelodus* (Aves: Phoenicopteriformes) from New Zealand. *Rec Aust Mus* 62:77-88

Worthy TH, Tennyson AJD, Scofield RP (2011) Fossils reveal an early Miocene presence of the aberrant gruiform Aves: Aptornithidae in New Zealand. *J Ornithol* 152:669-680

Zelenkov N, Dyke GJ (2008) The fossil record and evolution of Mousebirds (Aves: Coliiformes). *Palaeontology* 51 (6):1403-1418

Appendix 3.8.2. Table S2. Paleontological and geographical information for extinct relatives of recent families included in phylogenetic tree. **FAD:** FIRST APARITION DATA; **LAD** LAST APARITION DATA; **AO:** ANCESTRAL OCCUPATION; **Geog. Area:** Geographic Area. **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand; (*) Various species for the genera.

Clade	Fossil taxon	Geographic Area	Fossil Age (M.a) FAD	Fossil Age (M.a) LAD	References
Struthionidae	*Struthio coppensi*	(F)	23.30	20.44	(Mourer-Chauviré et al. 1996; Pickford 2004; Mayr 2009)
Rheidae	Rheidae indet.	(S)	61.60	59.20	(Alvarenga 1983; Tambussi 1995; Mayr 2009)
Tinamidae	*Crypturellus reai*	(S)	20.44	15.97	(Chandler 2012; Bertelli et al. 2014)
Dromaiidae	*Emuarius gidju*	(U)	28.10	23.30	(Boles 1992; Mayr 2009; Worthy et al. 2014)
Casuariidae	*Casuarius* sp.	(U)	3.60	2.58	(Hoch and Holm 1986; Alroy 2014)
Apterygidae	*Proapteryx micromeros*	(Z)	20.44	15.97	(Worthy et al. 2013)
Anseranatidae AO	*Anatalavis oxfordi*	(N) (E)	69.20	65.00	(Olson 1999a; Mayr 2014c)
Anseranatidae	*Eoanseranas handae*	(U)	28.10	20.44	(Worthy and Scanlon 2009)
Anhimidae AO	Anhimidae indet.	(U)	56.00	47.80	(Elzanowski and Boles 2012)
Anhimidae	*Chaunoides antiquus* *Loxornis clivus*	(S)	28.10	20.44	(Alvarenga 1999; Mayr 2009)
Anatoidea AO	*Vegavis iaai*	(T)	72.10	66.00	(Clarke et al. 2005)
Anatidae AO	*Romainvillia stehlini*	(E)	38.00	33.90	(Mayr 2009; Mayr and De Pietri 2013)
Anatidae	*Mionetta blanchardi* *Pinpanetta* sp. *(3)* *Australotadorna alecwilsoni* *Teleornis impressus*	(E) (U) (U) (S)	33.90	28.10	(Mayr 2008b, 2009)
Galliformes AO	Galliformes indet	(A)	59.20	47.80	(Hwang et al. 2010)
Megapodiidae	*Ngawupodius minya*	(U)	28.10	23.03	(Boles and Ivison 1999; Mayr 2009)
Cracidae AO	*Procrax brevipes*	(N)	38.00	33.90	(Mayr and Weidig 2004; Mayr 2009)
Cracidae	*Palaeonossax senectus*	(N)	33.90	28.10	(Wetmore 1956; Mayr 2009)

Numididae AO	*Telecrex grangeri*	(A)	38.00	33.90	(Olson 1974; Mayr 2009)
Numididae	*Numida* sp.	(F)	3.60	2.58	(Alroy 2014)
Phasianidae AO	*Palaeortyx gallica*	(E)	28.10	23.03	(Mourer-Chauviré 1992; Mayr et al. 2006; Mayr 2009)
Phasianidae	*Schaubortyx keltica*	(E)	29.00	27.50	(Mayr et al. 2006; Mayr 2009)
Odontophoridae	*Nanortyx inexpectatus*	(N)	38.00	33.90	(Mayr 2009)
Eurypygidae AO	*Eoeurypyga olsoni*	(N)	53.50	48.50	(Weidig 2003; Mayr 2009)
Rhynochetidae	*Rhynochetos orarius*	(U)	0.01	0.00	(Del Hoyo et al. 1996; Balouet and Olson 1989)
Podargidae AO	*Masillapodargus longipes*	(E)	41.30	38.00	(Mayr 2001; Mayr 2009; Nesbitt et al. 2011; Ksepka et al. 2013)
Steatornithidae AO	*Prefica nivea* *Euronyctibius kurochkini*	(N) (E)	56.00 47.80	47.80 38.00	(Mayr 1999; Mayr 2001; Mayr 2009; Nesbitt et al. 2011; Ksepka et al. 2013)
Nyctibiidae AO	*Paraprefica kelleri*	(E)	47.80	38.00	(Mayr 1999, 2009; Ksepka et al. 2013; Mayr 2014c)
Caprimulgidae AO	Caprimulgidae indet.	(N)	56.00	47.20	(Olson 1999b; Mayr 2009)
Caprimulgidae	*Ventivorus ragei*	(E)	40.40	37.20	(Mourer-Chauviré 1988, 1989; Mayr 2009)
Aegothelidae	*Aegotheles* sp.	(U)	19.00	16.00	(Worthy et al. 2007; Alroy 2014)
Trochilidae AO	*Parargornis messelensis*	(E)	56.00	47.80	(Mayr 2005; Mayr 2009; Ksepka et al. 2013)
Trochilidae	*Eurotrochilus inexpectatus*	(E)	33.90	28.10	(Mayr 2009; Mayr and Micklich 2010; Ksepka et al. 2013)
Apodidae AO	*Collocalia buday*	(E)	56.00	33.90	(Mayr and Peters 1999; Mayr 2009; Ksepka et al. 2013)
Phaethontidae	*Phaethusavis pelagicus*	(F)	56.00	47.80	(Bourdon et al. 2008)
Phoenicopteriformes AO	*Juncitarsus merkelli*	(E)	56.00	47.80	(Olson and Feduccia 1980; Ericson 1999; Mayr 2004, 2009, 2014a)

Phoenicopteridae AO	*Phoeniconotius eyrensis*	(U)	28.10	23.03	(Miller 1963; Mayr 2009, 2014a)
Phoenicopteridae	*Phoenicopterus* sp.	(E)	28.10	23.03	(Mayr 2009, 2014a)
Podicipediformes AO	Podicipediformes indet.	(A) (U)	28.10	20.44	(Kurochkin 1976; Vickers-Rich 1991)
Podicipedidae	*Miobaptus walteri*	(E)	20.44	15.97	(Švec 1982, 1984; Mayr 2004, 2009)
Pteroclidae AO	*Archaeoganga pinguis*	(E)	28.10	23.03	(Mourer-Chauviré 1993; Mlíkovský 2002; Mayr 2009)
Pteroclidae	*Leptoganga sepultus*	(E)	24.60	24.60	(Mourer-Chauviré 1993; Mlíkovský 2002; Mayr 2009, 2014c)
Columbidae AO	Columbidae indet.	(U)	28.10	23.00	(Vickers-Rich 1991; Worthy et al. 2007)
Opisthocomidae AO	*Protazin parisiensis*	(E)	34.00	33.00	(Mayr and De Pietri 2014; Mayr 2014c)
Opisthocomidae	*Hoazinavis lacustris*	(S)	28.00	20.44	(Mayr et al. 2011b; Mayr and De Pietri 2014)
Aramidae AO	*Badistornis aramus*	(N)	33.90	28.10	(Chandler and Wall 2001; Mayr 2009)
Aramidae	*Loncornis erectus*	(S)	28.00	0.00	(Agnolin 2004; Mayr 2009)
Gruidae AO	*Palaeogrus princeps* *Eobalearica tugarinovi*	(E) (A)	47.80	41.30	(Mlíkovský 2002; Mayr 2009)
Gruidae	Gruidae indet.	(N)	33.90	11.62	(Olson 1985; Mayr 2009)
Rallidae AO	*Songzia heidangkouensis*	(A)	56.00	47.80	(Hou 2003)
Rallidae	*Belgirallus oligocaenus* Rallidae indet.	(E) (F)	33.9	32.40	(Mayr and Smith 2001; Mayr 2009)
Heliornithidae AO	*Heliornis* sp.	(N)	15.97	11.62	(Olson 2003; Louchart et al. 2005)
Otididae AO	Otididae indet.	(F)	13.82	11.62	(Alroy 2014)
Otididae	*Otis bessarabensis*	(E)	13.10	11.20	(Sanchez Marco 1990; Mlíkovský 2002)
Cuculidae AO	*Eutreptodactylus itaboraiensis*	(S)	59.20	56.00	(Mayr et al. 2011a; Tambussi and Degrange 2013)
Cuculidae	*Chambicuculus pusillus*	(F)	47.00	41.30	(Mourer-Chauviré et al. 2013b; Mayr 2014c)
Musophagiformes AO	Musophagiformes indet.	(F)	33.90	28.10	(Rasmussen et al. 1987; Mayr 2009)

Gaviiformes AO	*Polarornis gregorii*	(T)	72.10	66.00	(Chatterjee 2002; Tambussi and Acosta Hospitaleche 2007; Mayr 2014c)
Gaviidae	*Colymbiculus udovichenkoi*	(E)	47.80	38.00	(Mayr and Zvonok 2011; Mayr et al. 2013; Mayr 2014c)
Sphenisciformes AO	*Waimanu manneringi*	(Z)	61.00	59.00	(Ksepka et al. 2006; Slack et al. 2006; Clarke et al. 2007; Mayr 2009; Ksepka and Clarke 2010a; Mayr 2014c)
Spheniscidae	*Delphinornis larseni* *Perudyptes devriesi*	(T) (S)	47.8	33.9 41.3	(Clarke et al. 2007; Mayr 2009; Ksepka and Clarke 2010a)
Procellariiformes AO	*Lonchodytes pterygius*	(N)	72.10	65.00	(Hope 2002; Mayr 2009)
Hydrobatidae	*Oceanodroma hubbsi*	(N)	11.62	7.24	(Alroy 2014)
Diomedeidae	*Tydea septentrionalis*	(E)	33.90	28.10	(Mayr and Smith 2012)
Procellariidae AO	*Argyrodyptes microtarsus*	(S)	38.00	28.10	(Agnolin 2004; Mayr 2009; Tambussi and Degrange 2013)
Pelecanoididae	*Pelecanoides miokuaka*	(Z)	20.44	15.97	(Worthy et al. 2007)
Ciconiidae AO	*Eociconia sangequanensis*	(A)	47.80	38.00	(Hou 2003; Mayr 2009)
Ciconiidae	*Palaeoephippiorhynchus dietric*	(F)	33.9	28.10	(Rasmussen et al. 1987; Olson 1985; Mayr 2009, 2014c)
Fregatidae AO	*Limnofregata azygosternon*	(N)	56.00	47.80	(Olson and Matsouka 2005; Mayr 2009, 2014c)
Sulidae AO	*Masillastega rectirostris*	(E)	48.60	46.00	(Mayr 2002b, 2009, 2014c)
Sulidae	*Eostega lebedinskyi*	(E)	37.20	33.90	(Mlíkovský 2002, 2009)
Anhingidae AO	*Liptornis hesternus*	(S)	15.97	13.82	(Tambussi 2011; Tambussi and Degrange 2013)
Phalacrocoracidae AO	Phalacrocoracidae indet.	(N)	72.10	66.00	(Hope 2002; Mayr 2009)
Phalacrocoracidae	*Piscator tenuirostris*	(E)	38.0	33.90	(Mayr 2009, 2014c)
Pelecaniformes AO	*Torotix clemensi*	(N)	69.20	66.00	(Hope 2002; Mayr 2009)
Ardeidae AO	*Calcardea junnei*	(N)	56.00	47.80	(Sallaberry et al.

					2010)
Ardeidae	*Gnotornis aramiellus* *Nycticorax* sp.	(N) (E)	33.90	28.1	(Olson 1985; Mayr 2009, 2014c)
Threskiornithidae AO	*Rhynchaeites messelensis*	(E)	56.00	41.30	(Mayr 2002a, 2014c)
Pelecanidae	*Pelecanus* sp.	(E)	33.90	0.00	(Louchart et al. 2010; Altamirano-Sierra 2013; Mayr 2014c)
Balaenicipitidae	*Goliathia andrewsi*	(F)	38.00	28.10	(Olson 1985; Mayr 2009, 2014c)
Scopidae	*Scopus xenops*	(F)	5.33	3.60	(Olson 1984, 1985; Alroy 2014)
Burhinidae AO	*Wilaru tedford*	(U)	24.00	26.00	(Boles et al. 2013)
Burhinidae	*Genucrassum bransatensis*	(E)	23.4	23.03	(De Pietri and Scofield 2013; Smith 2015)
Recurvirostridae AO	*Recurvirostra sanctaeneboulae*	(E)	56.00	47.80	(Mourer-Chauviré 1978; Mlíkovský 2002; Mayr 2009)
Haematopodidae AO	*Haematopodidae indet.*	(E)	22.50	20.44	(De Pietri et al. 2013)
Haematopodidae	*Haematopodus* sp.	(N)	5.33	3.60	(De Pietri et al. 2013)
Charadriidae AO	*Jiliniornis huadianensis*	(A)	47.80	38.00	(Hou and Ericson 2002; Smith 2015)
Scolopacidae AO	*Paractitis bardi*	(N)	37.20	33.90	(Olson 1999b; Mayr 2009)
Scolopacidae	Scolopacidae indet.	(E)	33.9	0.00	(Roux 2002; Mayr 2009)
Rostratulidae AO	*Rostratula pulia*	(E)	17.20	16.40	(Mlíkovský 2002)
Jacanidae AO	*Nupharanassa totularia*	(F)	38.00	28.00	(Rasmussen et al. 1987; Mayr 2009; Smith 2015)
Pedionomidae	*Oligonomis milleri*	(U)	26.00	24.00	(De Pietri et al. 2014)
Turnicidae AO	*Turnipax oechslerorum*	(E)	34.90	28.10	(Mayr and Knopf 2007; Smith 2015)
Glareolidae AO	*Boutersemia* sp.	(E)	33.90	28.10	(Mayr and Smith 2001; De Pietri et al. 2011a)
Glareolidae	*Mioglareola gregaria* *Paractiornis* sp.	(E) (N)	23.03	15.97	(De Pietri et al. 2011a)
Panalcidae	Panalcidae incertae sedis	(N)	38.00	33.90	(Chandler and Parmley 2002; Wijnker and Olson

					2009; Smith 2011; Smith 2015)
Alcidae	*Miocepphus bohaski*	(N)	20.43	15.97	(Wijnker and Olson 2009; Smith and Clarke 2014; Smith 2015)
Stercorariidae	*Stercorarius* sp.	(N)	5.33	3.60	(Olson and Rasmussen 2001)
Laridae	*Larus dolnicensis*	(E)	17.10	16.40	(Mlíkovský 2002; De Pietri et al. 2011a)
Cathartoidea AO	*Diatropornis ellioti*	(E)	41.30	33.90	(Mourer-Chauviré 2002, 2006; Mayr 2009, 2011, 2014c)
Cathartidae	*Phasmagyps patritus*	(N)	38	33.90	(Mayr 2009, 2011, 2014c)
Sagittariidae AO	*Pelargopappus schlosseri*	(E)	33.90	23.03	(Mourer-Chauviré and Cheneval 1983; Mayr 2009)
Accipitridae AO	*Milvoides kempi* *Accipitridae indet.*	(E) (F)	38.00	33.90	(Mayr 2009, 2014c)
Accipitridae	*Buteo* sp.	(N) (A)	33.90	0.00	(Kurochkin 1976; Mayr 2009)
Pandionidae AO	Pandionidae indet.	(E)(F)	38.00	28.10	(Mayr 2009, 2014c)
Pandionidae	*Pandion* sp.	(N)	15.97	0.00	(Olson 1985; Mayr 2009)
Strigidae	*Myoglaux poirrieri*	(E)	21.70	17.50	(Mlíkovský 2002; Kurochkin and Dyke 2012)
Tytonidae AO	*Necrobyas arvernensis* *Selenornis henrici*	(E)	40.00	24.00	(Mlíkovský 2002; Mayr 2009; Kurochkin and Dyke 2012)
Tytonidae	*Basityto rummeli*	(E)	21.70	17.20	(Mlíkovský 2002; Kurochkin and Dyke 2012)
Leptosomatidae AO	*Plesiocathartes* sp.	(N) (E)	56.00	41.30	(Mayr 2008a, 2009, 2014c)
Trogoniformes AO	*Septentrogon madseni*	(E)	54.50	54.00	(Lindow and Dyke 2006; Mayr 2009, 2014c)
Trogonidae	*Paratrogon gallicus*	(E)	21.70	19.50	(Mlíkovský 2002; Mayr 2011)
Upupidae	*Upupa* sp.	(E)	19.50	17.2	(Mlíkovský 2002)
Phoeniculidae	*Phirriculus pinicola*	(E)	21.7	16.40	(Mlíkovský 2002; Mayr 2011)
Bucerotidae AO	*Tockus* sp.	(F)	15.00	14.00	(Brunet 1971; Boev

	Bucorvus brailloni		11.62	5.30	and Kovachev 2007; Mayr 2014b)
Bucerotidae	*Euroceros bulgaricus*	(E)	8.90	7.40	(Boev and Kovachev 2007; Mayr 2011)
Meropidae	*Merops radoboyensis*	(E)	13.10	0.00	(Mlíkovský 2002)
Coraciidae	*Miocoracias chenevali*	(E)	21.7	19.5	(Mourer-Chauviré et al. 2013a)
Todidae AO	*Palaeotodus* sp.	(N)(E)	38.00	28.10	(Mayr 2009; Mayr and Micklich 2010)
Alcediniformes AO	*Quasisyndactylus longibrachis*	(E)	47.80	38.00	(Mayr 2009, 2014c)
Momotidae AO	*Protornis glarniensis*	(E)	33.90	28.10	(Mlíkovský 2002; Mayr 2009, 2011)
Momotidae	Momotidae indet.	(N)	10.3	4.90	(Becker 1986; Mayr 2011)
Alcedinidae	*Alcedo atthis*	(E)	0.126	0.00	(Mlíkovský 2002; Sanchez Marco 2004)
Ramphastidae AO	*Rupelramphastoides knopfi*	(E)	28.10	23.03	(Mayr 2009, 2011)
Ramphastidae	*Capitonides* sp.	(E)	20.44	13.00	(Mayr and Gregorová 2012)
Indicatoridae	*Indicatoridae indet.*	(F)	5.333	3.66	(Olson 1985; Mayr and Gregorová 2012)
Picidae	*Piculoides saulcetensis*	(E)	23.03	20.5	(De Pietri et al. 2011b)
Coliidae AO	*Mesillacolius brevidactylus* *Celericolius acriala*	(E) (N)	48.60 52.60	46.0 50.6	(Zelenkov and Dyke 2008; Ksepka and Clarke 2010b; Mayr 2013)
Coliidae	*Limnatornis paludicola* Coliidae indet.	(E) (F)	21.70 23.03	19.5 20.4	(Mourer-Chauviré 2008; Zelenkov and Dyke 2008; Mayr 2013)
Cariamidae	*Noriegavis santacrucensis*	(S)	23.03	16.00	(Noriega et al. 2009; Mayr and Noriega 2013)
Falconidae AO	Falconidae indet.	(T)	47.80	41.30	(Tambussi et al. 1995; Noriega et al. 2011)
Falconidae	*Badiostes patagonicus* *Thegornis musculosus*	(S) (S)	15.97 16.5	11.62 16.0	(Becker 1987; Olson 1985; Suárez and Olson 2001; Martín Cenizo et al. 2012)
Cacatuidae	*Cacatua* sp.	(U)	15.97	11.62	(Boles 1993; Waterhouse 2006)
Psittacidae	*Nelepsittacus daphneleeae*	(Z)	19	16	(Ksepka et al. 2011; Worthy et al. 2012)
Passeriformes	Passeriformes indet.	(U)	55.00	47.8	(Mayr 2009, 2014c)

Hemiprocnidae	*Family without fossil record*	(A) (I)	0.01	0.00	(Del Hoyo et al. 1999; Ksepka et al. 2013)
Mesitornithidae	*Family without fossil record*	(M)	0.01	0.00	(Del Hoyo et al. 1996)
Psophiidae	*Family without fossil record*	(S)	0.01	0.00	(Del Hoyo et al. 1996; Ribas et al. 2011)
Chionidae	*Family without fossil record*	(S)(T)	0.01	0.00	(Del Hoyo et al. 1996)
Pluvianellidae	*Family without fossil record*	(S)	0.01	0.00	(Del Hoyo et al. 1996)
Pluvianidae	*Family without fossil record*	(F)	0.01	0.00	(Del Hoyo et al. 1996)
Ibidorhynchidae	*Family without fossil record*	(A)	0.01	0.00	(Del Hoyo et al. 1996)
Thinocoridae	*Family without fossil record*	(S)	0.01	0.00	(Del Hoyo et al. 1996)
Dromadidae	*Family without fossil record*	(F)(A)	0.01	0.00	(Del Hoyo et al. 1996)
Brachypteraciidae	*Family without fossil record*	(M)	0.01	0.00	(Del Hoyo et al. 2001)
Galbulidae	*Family without fossil record*	(N)(S)	0.01	0.00	(Del Hoyo et al. 2002)
Bucconidae	*Family without fossil record*	(N)(S)	0.01	0.00	(Del Hoyo et al. 2002)

REFERENCES

Agnolin FL (2004) Revisión sistemaática de algunas aves deseadenses (Oligoceno Medio) descritas por Ameghino en 1899. *Rev Mus Argent Cienc Nat* 6: 236-244

Alroy J (2014) *Paleobiology Database*. Macquarie University. http://paleodb.org. visited during 2014

Altamirano-Sierra AJ (2013) Primer registro de pelícano (Aves: Pelecanidae) para el Mioceno tardío de la formación Pisco, Perú. *Bulletin de l'institut Français d´Études Andines* 42 (1):1-12

Alvarenga H (1983) Uma ave ratitae do Paleoceno Brasileiro: bacia calcária de Itaboraí, Estado do Rio de Janeiro, Brasil. *Bol Mus Nac Geol* 41:1-8

Alvarenga H (1999) A fossil screamer (Anseriformes: Anhimidae) from the middle Tertiary of southeastern Brazil.In: Olson SL (ed) Avian paleontology at the close of the 20th century. Proceedings of the 4th international meeting of the Society

of Avian Paleontology and Evolution., vol 89. *Smithson Contrib Paleobiol* Washington D.C., pp 223-230

Balouet JC, Olson SL (1989) Fossil birds from Late Quaternary deposits in New Caledonia. *Smithson Contrib Zool* (469):1-38

Becker J (1986) A fossil Motmot (Aves: Momotidae) from the Late Miocene of Florida. *Condor* 88:478-482

Becker J (1987) Revision of "*Falco*" *ramenta* Wetmore and the Neogene evolution of the Falconidae. *The Auk* 104:270-276

Bertelli S, Chiappe LM, Mayr G (2014) Phylogenetic interrelationships of living and extinct Tinamidae, volant palaeognathous birds from the New World. *Zool J Linn Soc* 172 (1):145-184

Boev Z, Kovachev D (2007) *Euroceros bulgaricus* gen. nov., sp. nov. from Hadzhidimovo (SW Bulgaria) (Late Miocene): the first European record of Hornbills (Aves: Coraciiformes).*Geobios*:39-49

Boles WE (1992) Revision of *Dromaius gidju* Patterson and Rich 1987 from Riversleigh, north- western Queensland, Australia, with a reassessment of its generic position. In: Campbell KE (ed) *Papers in avian paleontology honoring Pierce Brodkorb*, vol 36. Nat Hist Mus Los Angeles Cty Sci Ser pp 195-208

Boles WE (1993) A new cockatoo (Psittaciformes: cacatuidae) from the tertiary of Riversleigh, northwestern Queensland, and an evaluation of rostral characters in the systematics of parrots. *Ibis* 135:8-18

Boles WE, Finch MA, Hofheins RH, Vickers-Rich P, Walters M, Rich TH (2013) A fossil stone-curlew (Aves: Burhinidae) from the Late Oligocene/Early Miocene of South Australia. In: Göhlich UB, Kroh A (eds) *Paleornithological Research* 2013. Proceed. 8th Internat. Meeting Society of Avian Paleontology and Evolution. Verlag Naturhistorisches Museum Wien, Vienna, Austria, pp 43-62

Boles WE, Ivison TJ (1999) A new dwarf megapode (Galliformes: Megapodiidae) from the late Oligocene of central Australia. In: Olson SL (ed) Avian paleontology at the close of the 20th century: Proceedings of the 4th international meeting of the Society of Avian Paleontology and Evolution, vol 89. *Smithson Contrib Paleobiol*. Washington, D.C., pp 199-206

Bourdon E, Amaghzaz M, Bouya B (2008) A new seabird (Aves, cf. Phaethontidae) from the Lower Eocene phosphates of Morocco. *Geobios* 41:455-459

Brunet J (1971) Oiseaux miocénes de Beni Mellal (Maroc): un complemént à leur étude. *Notes et Mém Service géol Maroc* 31:109-111

Chandler RM (2012) A New Species of Tinamou (Aves: Tinamiformes, Tinami- dae) from the Early-Middle Miocene of Argentina. Palarch's *J Vertebr Palaeontol* 9 (2):1-8

Chandler RM, Parmley D (2002) The earliest North American record of an auk (Aves: Alcidae) from the Late Eocene of central Georgia. *Oriole* 68:7-9

Chandler RM, Wall WP (2001) The first record of bird eggs from the early Oligocene (Orellan) of North America. *Proceedings of the 6th fossil resource conference Geol Resour Div Tech Rep* NPS/NRGRD/GRDTR-01:23-26

Chatterjee S (2002) The morphology and systematics of *Polarornis*, a Cretaceous loon (Aves: Gaviidae) from Antarctica. In: Zhou Z, Zhang F (eds) *Proceedings of the 5th symposium of the society of avian paleontology and evolution*. Beijing,

Clarke JA, Ksepka DT, Stucchi M, Urbina M, Giannini N, Bertelli S, Narváez Y, Boyd CA (2007) Paleogene equatorial penguins challenge the proposed relationship between biogeography, diversity, and Cenozoic climate change. *Proc Natl Acad Sci USA* 104 (28):11545-11550.

Clarke JA, Tambussi CP, Noriega JI, Erickson GM, Ketcham (2005) Definitive fossil evidence for the extant avian radiation in the Cretaceous. *Nature* 433:305-308

De Pietri VL, Camens AB, Worthy TH (2014) A Plains-wanderer (Pedionomidae) that did not wander plains: a new species from the Oligocene of South Australia. *Ibis* 11:1-7.

De Pietri VL, Costeur L, Güntert M, Mayr G (2011a) A revision of the Lari (Aves, Charadriiformes) from the early Miocene of Saint Gérand le Puy (Allier, France). *J Vertebr Paleontol* 31:812-828

De Pietri VL, Güntert M, Mayr G (2013) A Haematopus-like skull and other remains of Charadrii (Aves, Charadriiformes) from the Early Miocene of Saint Gérand le Puy (Allier, France). In: Göhlich UB, Kroh A (eds) *Paleornithological Research* 2013. Proceed. 8th Internat. Meeting Society of Avian Paleontology and Evolution. Verlag Naturhistorisches Museum Wien, Vienna, Austria, pp 93-102

De Pietri VL, Manegold A, Costeur L, Mayr G (2011b) A new species of woodpecker (Aves; Picidae) from the early Miocene of Saulcet (Allier, France). *Swiss J Palaeontol* 130:307-314

De Pietri VL, Scofield RP (2013) The earliest European record of a Stone-curlew (Charadriiformes, Burhinidae) from the late Oligocene of France. *J Ornithol* 155:421-426

Del Hoyo J, Elliott A, Sargatal J (1996) *Hoatzin to Auks. Handbook of the Birds of the World*, vol 3. Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (1999) *Barn-Owls to Hummingbirds. Handbook of the Birds of the World*, vol 5. Lynx edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (2001) *Mousebirds to Hornbills. Handbook of the Birds of the World*, vol 6. Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (2002) *Jacamars to Woodpeckers. Handbook of the Birds of the World*, vol 7. Lynx Edicions, Barcelona

Elzanowski A, Boles WE (2012) Australia's oldest Anseriform fossil: a quadrate from the Early Eocene Tingamarra Fauna. *Palaeontology* 55 (4):903-911.

Ericson PGP (1999) New material of *Juncitarsus* (Phoenicopteriformes), with a guide for differentiating that genus from the Presbyornithidae (Anseriformes). In: Olson SL (ed) Avian paleontology at the close of the 20th century: Proceedings of the 4th international meeting of the Society of Avian Palaeontology and Evolution, vol 89. *Smithson Contrib Paleobiol.* Washington D.C., pp 245-251

Hoch E, Holm PM (1986) New K/Ar age determinations of the Awe Fauna Gangue, Papua New Guinea: consequences for Papuaustralian late Cenozoic biostratigraphy. *Modern Geology* 10:181-195

Hope S (2002) The Mesozoic radiation of Neornithes. In: Chiappe LM, Witmer LM (eds) *Mesozoic birds: above the heads of dinosaurs.* University of California Press, Berkeley, p 520

Hou L-H (2003) *Fossil birds of China*. Yunnan Science and Technology, Kunming

Hou L-H, Ericson PGP (2002) A Middle Eocene shorebird from China. *Condor* 104:896-899

Hwang SH, Mayr G, Bolortsetseg M (2010) The earliest galliform bird in Asia, from the Late Paleocene-Early Eocene of the Gobi Desert, Mongolia. *J Vertebr Paleontol* 30:1642-1644

Ksepka DT, Bertelli S, Giannini NP (2006) The phylogeny of the living and fossil Sphenisciformes (penguins) *Cladistics* 22:412-441

Ksepka D, Clarke JA (2010a) The basal Penguin (Aves: Sphenisciformes) *Perudyptes devriesi* and a phylogenetic evaluation of the Penguin Fossil Record. *Bull Am Mus Nat Hist* 337:1-77

Ksepka DT, Clarke JA (2010b) New fossil mousebird (Aves: Coliiformes) with feather preservation provides insight into the ecological diversity of an Eocene North American avifauna. *Zool J Linn Soc* 160:685-706

Ksepka DT, Clarke JA, Grande L (2011) Stem parrots (Aves, Halcyornithidae) from the Green River formation and a combined phylogeny of Pan-Psittaciformes. *J Paleontol* 85 (5):835-852

Ksepka DT, Clarke JA, Nesbitt SJ, Kulp FB (2013) Fossil evidence of wing shape in stem relative of swifts and hummingbirds (Aves, Pan-Apodiformes). *Proc R Soc Lond B* 280:20130580

Kurochkin EN (1976) A survey of the Paleogene birds of Asia. *Smithson Contrib Paleobiol* 27:75-86

Kurochkin EN, Dyke GJ (2012) The First Fossil Owls (Aves: Strigiformes) from the Paleogene of Asia and a Review of the Fossil Record of Strigiformes. *Paleontol J* 45 (4):445-458

Lindow BEK, Dyke GJ (2006) Bird evolution in the Eocene: climate change in Europe and a Danish fossil fauna. *Biol Rev* 81:483-499

Louchart A, Mourer-Chauviré C, Vignaud P, Taisso MacKaye H, Brunet M (2005) A finfoot from the Late Miocene of Toros Menalla (Chad, Africa): Palaeobiogeographical and palaeoecological implications. *Palaeogeogr Palaeoclimatol Palaeoecol* 222 (1–2):1-9.

Louchart A, Tourment N, Carrier J (2010) The earliest know pelican reveals 30 million years of evolutionary stasis in beak morphology. *J Ornithol* 152 (1):15-20

Martín Cenizo M, Tambussi CP, Moltalvo CI (2012) Late Miocene continental birds from the Cerro Azul Formation in the Pampean region (central-southern Argentina). Alcheringa: An Australasian *J Palaeontol* 36 (1):47-68

Mayr G (1999) Caprimulgiform birds from the Middle Eocene of Messel (Hessen, Germany). *J Vertebr Paleontol* 19:512-532

Mayr G (2001) Comments on the osteology of *Massillapodargus longipipes* Mayr 1999 and *Paraprefica major* Mayr 1999, caprimulgiform birds from the Middle Eocene of Messel (Hessen, Germany). *N Jb Geol Palaöntol, Mh* 2001:65-76

Mayr G (2002a) A contribution to the osteology of the Middle Eocene ibis *Rhynchaeites messelensis* (Aves: Threskiornithidae: Rhynchaeitinae nov. subfam.). *N Jb Geol Palaöntol, Mh* 2002:501-512

Mayr G (2002b) A skull of a new pelecaniform bird from the Middle Eocene of Messel, Germany. *Acta Palaeontol Pol* 47:507-512

Mayr G (2004) Morphological evidence for sister group relationship between flamingos (Aves: Phoenicopteridae) and grebes (Podicipedidae). *Zool J Linn Soc* 140:157-169

Mayr G (2005) Fossil hummingbirds in the Old World. *Biologist* 52 (1):12-16

Mayr G (2008a) The Madagascan "Cuckoo-roller" (Aves: Leptosomidae) is not a roller: notes on the phylogenetic affinities and evolutionary history of a "living fossil". *Acta Ornithol (Wars)* 43 (2):226-230

Mayr G (2008b) Phylogenetic affinities and morphology of the late Eocene anseriform bird *Romainvillia stehlini* Lebedinsky, 1927. *N Jahrb Geol Paläeontol Abh* 248:365-380

Mayr G (2009) *Paleogene fossil birds.* Springer, Heilderberg

Mayr G (2011) Two-phase extinction of "Southern Hemispheric" birds in the Cenozoic of Europe and the origin of the Neotropic avifauna. *Palaeobiodivers Palaeoenviron* 91:325-333

Mayr G (2013) Late Oligocene mousebird converges on parrots in skull morphology. *Ibis* 155:384-396

Mayr G (2014a) The Eocene *Juncitarsus*: its phylogenetic position and significance for the evolution and higher-level affinities of flamingos and grebes. *Comptes Rendus Palevol* 13:9-18

Mayr G (2014b) On the Middle Miocene avifauna of Maboko Island, Kenya. *Geobios* 47:133-146

Mayr G (2014c) The origins of crown group birds: Molecules and Fossils. *Palaeontology* 57 (2):231-241

Mayr G, Alvarenga H, Clarke J (2011a) An *Elaphrocnemus*-like landbird and other avian remains from the late Paleocene of Brazil. *Acta Palaeontol Pol* 56:679-684

Mayr G, Alvarenga H, Mourer-Chauviré C (2011b) Out of Africa: fossils shed light on the origin of the hoatzin, an iconic Neotropic bird. *Naturwissenschaftlichen* 98:961-966

Mayr G, De Pietri VL (2013) A goose-sized anseriform bird from the Late Oligocene of France: the youngest record and largest species of Romainvilliinae. *Palaöont Z* 87:423-430

Mayr G, De Pietri VL (2014) Earliest and first Northern Hemispheric hoatzin fossils substantiate Old World origin of a "Neotropic endemic". *Naturwissenschaften* 101:143-148

Mayr G, Gorobets L, Zvonok E (2013) The tarsometatarsus of the Middle Eocene loon *Colymbiculus udovichenkoi*. In: Göhlich UB, Kroh A (eds) *Paleornithological Research* 2013, Proceed. 8th Internat. Meeting Society of Avian Paleontology and Evolution. Verlag Naturhistorisches Museum Wien, Vienna, Austria, pp 17- 22

Mayr G, Gregorová R (2012) A tiny stem group representative of Pici (Aves, Piciformes) from the early Oligocene of the Czech Republic. *Paläontol Z* 86:333-343

Mayr G, Knopf C (2007) A stem lineage representative of buttonquails from the Lower Oligocene of Germany: fossil evidence for a charadriiform origin of the Turnicidae. *Ibis* 149:774-782

Mayr G, Micklich N (2010) New specimens of the avian taxa *Eurotrochilus* (Trochilidae) and *Palaeotodus* (Todidae) from the early Oligocene of Germany. *Paläontol Z* 84:387-395

Mayr G, Noriega JI (2013) A well-preserved partial skeleton of the poorly known early Miocene seriema *Noriegavis santacrucensis* (Aves, Cariamidae). *Acta Palaeontol Pol* 60 (3), 2015: 589-598.

Mayr G, Peters DS (1999) On the systematic position of the Middle Eocene swift *Aegialornis szarskii* Peters 1985 with description of a new swift-like bird from Messel (Aves, Apodiformes). *N Jb Geol Palaöntol, Mh* 1999:312-320

Mayr G, Poschmann M, Wuttke M (2006) A nearly complete skeleton of the fossil galliform bird *Palaeortyx* from the late Oligocene of Germany. *Acta Ornithol* 41:129-135

Mayr G, Smith R (2001) Ducks, rails, and limicoline waders (Aves: Anseriformes, Gruiformes, Charadriiformes) from the Lowermost Oligocene of Belgium. *Geobios* 34:547-561

Mayr G, Smith T (2012) A fossil albatross from the Early Oligocene of the North Sea basin. *The Auk* 129 (1):87-95

Mayr G, Weidig I (2004) The Early Eocene bird *Gallinuloides wyomingensis*: a stem group representative of Galliformes. *Acta Palaeontol Pol* 49 (2):211-217

Mayr G, Zvonok E (2011) Middle Eocene Pelagornithidae and Gaviiformes (Aves) from the Ukrainian Paratethys. *Palaeontology* 54:1347-1359

Miller AH (1963) The fossil flamingos of Australia. *Condor* (65):289-299

Mlíkovský Jí (2002) *Cenozoic Birds of the World*, vol Part 1: Europe. Praha: Ninox press,

Mlíkovský Jí (2009) Evolution of the Cenozoic marine avifaunas of Europe. *Ann Naturhist Mus Wien* 111A:357-374

Mourer-Chauviré (1992) The Galliformes (Aves) from the Phosphorites du Quercy (France): systematics and biostratigraphy. In: Campbell KE (ed) *Papers in avian paleontology honoring Pierce Brodkorb*, vol 36. Nat Hist Mus Los Angeles Cty Sci Ser, pp 67-95

Mourer-Chauviré C (1978) La poche à phosphate de Sainte-Néboule (Lot) et sa faune de Vertébrés du Ludien supérieur. 6. Oiseaux. *Palaeovertebrata* 8:217-229

Mourer-Chauviré C (1988) Le gisement du Bretou (Phosphorites du Quercy, Tarn et Garonne, France) et sa faune des vertebres de l'Eocene superieur; 2. Oiseaux. *Palaeontogr Abt A Palaeozool-Stratigr* 205 (1-6):29-50

Mourer-Chauviré C (1989) Les Caprimulgiformes et les Coraciiformes de l'Éocène et de l'Oligocène des Phosphorites du Quercy et description de deux genres nouveaux de Podargidae et Nyctibiidae. In: Ouellet H (ed) *Acta XIX congressus internationalis ornithologici*. University of Ottawa Press, Ottawa, pp 2047-2055

Mourer-Chauviré C (1993) Les gangas (Aves, Columbiformes, Pteroclidae) du Paléogène et du Miocène inférieur de France. *Palaeovertebrata* 22:73-98

Mourer-Chauviré C (2002) Revision of the Cathartidae (Aves, Ciconiiformes) from the Middle Eocene to the Upper Oligocene Phosphorites du Quercy, France. In: Zhou Z, Zhang F (eds) *Proc 5th Symp Soc Avian Paleontology and Evolution*. Science Press, Beijing, pp 97-111

Mourer-Chauviré C (2006) The avifauna of the Eocene and Oligocene Phosphorites du Quercy (France): an updated list. *Strata sér 1 Commun* 13:135-149

Mourer-Chauviré C (2008) Birds (Aves) from the Early Miocene of the Northern Sperrgebiet. Namibia. *Memoir Geol Surv Namibia* 20:147-167

Mourer-Chauviré C (2013) New data concerning the familial position of the genus *Euronyctibius* (Aves, Caprimulgiformes) from the paleogene of the Phosphorites du Quercy, France. *Paleontol J* 47 (11):1315-1322

Mourer-Chauviré C, Cheneval J (1983) Les Sagittariidae fossiles (Aves, Accipitriformes) de l'Oligocène des Phosphorites du Quercy et du Miocène inférieur du Saint-Gérand-le-Puy. *Geobios* 16:443-459

Mourer-Chauviré C, Peyrouse J-B, Hugueney M (2013a) A new roller (Aves: Coraciiformes s. s.: Coraciidae) from the Early Miocene of the Saint-Gérand le Puy area, Allier, France. In: Göhlich UB, Kroh A (eds) *Paleornithological Research* 2013. Proceed. 8th Internat. Meeting Society of Avian Paleontology and Evolution. Verlag Naturhistorisches Museum Wien, Vienna, Austria., pp 81-92

Mourer-Chauviré C, Senut B, Pickford M, Mein P (1996) Le plus ancien représentant du genre *Struthio* (Aves, Struthionidae), *Struthio coppensi* n. sp., du Miocène inférieur de Namibie. *Comptes Rendus Acad Sci Paris* 322:325-332

Mourer-Chauviré C, Tabuce R, Essid EM, Marivaux L, Khayati H, Vianey-Liaud M, Haj Ali MB (2013b) A new taxon of stem group Galliformes and the earliest record for stem group Cuculidae from the Eocene of Djebel Chambi, Tunisia. In: Göhlich UB, Kroh A (eds) *Paleornithological Research* 2013. Proceed. 8th Internat. Meeting Society of Avian Paleontology and Evolution. Verlag Naturhistorisches Museum Wien, Vienna, Austria, pp 1-16

Nesbitt SJ, Ksepka DT, Clarke JA (2011) Podargiform Affinities of the Enigmatic *Fluvioviridavis platyrhamphus* and the Early Diversification of Strisores (''Caprimulgiformes'' + Apodiformes). *PLoS ONE* 6 (11):e26350

Noriega JI, Areta JI, Vizcaíno SF, Bargo S (2011) Phylogeny and taxonomy of the Patagonian Miocene Falcon *Thegornis musculosus* Ameghino, 1895 (Aves: Falconidae). *J Paleontol* 85 (6):1089-1104

Noriega JI, Vizcaíno SF, Bargo MS (2009) First record and a new species of Seriema (Aves: Ralliformes: Cariamidae) from Santacrucian (Early-Middle Miocene) beds of Patagonia. *J Vertebr Paleontol* 29 (2):620-626

Olson SL (1974) *Telecrex* restudied: a small Eocene guineafowl. *Wilson Bull* 86:246-250

Olson SL (1984) A Hamerkop from the early Pliocene of South Africa (Aves: Scopidae). *Proc Biol Soc Wash* 97:736-740

Olson SL (1985) The fossil record of birds. In: Farner DS, King JR, Parkes KC (eds) *Avian Biology*, vol 8. Academic Press, NewYork, pp 79-238

Olson SL (1999a) The anseriform relationships of *Anatalavis,* Olson and Parris (Anseranatidae), with a new species from the Lower Eocene London Clay. In: Olson SL (ed) Avian paleontology at the close of the 20th century. Proceedings of the 4th International Meeting of the Society of Avian Paleontology and Evolution. *Smithson Contrib Paleobiol*. Washington D.C., pp 231-243

Olson SL (1999b) Early Eocene birds from eastern North America: a faunule from the Nanjemoy Formation of Virginia. In: Weems RE, Grimsley GJ (eds) E*arly Eocene vertebrates and plants from the Fisher/Sullivan Site (Nanjemoy Formation) Stafford County, Virginia*, vol 152. Va Div Miner Resour Publ, pp 123-132

Olson SL (2003) First fossil record of a finfoot (Aves: Heliornithidae) and its biogeographical significance. *Proc Biol Soc Wash* 116 (3):732-736

Olson SL, Feduccia A (1980) Relationships and evolution of flamingos (Aves: Phoenicopteridae). *Smithson Contrib Zool* 316:1-73

Olson SL, Matsouka H (2005) New specimens of the early Eocene frigatebird *Limnofregata* (Pelecaniformes: Fregatidae), with the description of a new species. *Zootaxa* 1046:1-15

Olson SL, Rasmussen PC (2001) Miocene and Pliocene birds from the Lee Creek Mine, North Carolina. *Smithson Contrib Paleobiol* 90:233-365

Pickford M (2004) Southern Africa: a cradle of evolution. *S Afr J Sci* 100 (March/April):205-214

Rasmussen DT, Olson SL, Simons EL (1987) Fossil birds from the Oligocene Jebel Qatrani Formation, Fayum Province, Egypt. *Smithson Contrib Paleobiol* 62:1-20

Ribas CC, Aleixo A, Nogueira ACR, Miyaki CY, Cracraft J (2011) A palaeobiogeographic model for biotic diversification within Amazonia over the past three million years. *Proc R Soc Lond B*:1-9

Roux T (2002) Deux fossiles d'oiseaux de l'Oligocène inférieur du Luberon. *Courr Sci Parc Nat Reg Luberon* 6:38-57

Sallaberry MA, Yury-Yañez RE, Otero R, Soto-Acuña S, Torres G T (2010) Eocene Birds from the Western Margin of Southernmost South America. *J Paleontol* 84 (6):1061-1070

Sánchez Marco A (1990) A new bustard (Otididae; Aves) from the early Pliocene of Layna (Soria, Spain). *Paleontol i Evol* 23:223-229

Sánchez Marco A (2004) Avian zoogeographical patterns during the Quaternary in the Mediterranean Region and paleoclimatic interpretation. *Ardeola* 51 (1):91-132

Slack KE, Jones CM, Ando T, Harrison GL, Fordyce RE, Arnason U, Penny D (2006) Early penguin fossils, plus mitochondrial genomes, calibrate avian evolution. *Mol Biol Evol* 23:1144-1155

Smith NA (2011) Taxonomic revision and phylogenetic analysis of the flightless Mancallinae (Aves, Pan-Alcidae). *ZooKeys* 91:1-116

Smith NA (2015) Sixteen vetted fossil calibrations for divergence dating of Charadriiformes (Aves, Neognathae). *Palaeontol Electron* 18:1-18

Smith NA, Clarke JA (2014) Systematics and evolution of the Pan-Alcidae (Aves, Charadriiformes). *J Avian Biol* 46 (2):125-140

Suárez W, Olson SL (2001) A remarkable new species of small falcon from the Quaternary of Cuba (Aves: Falconidae: *Falco*). *Proc Biol Soc Wash* 114 (1):34-41

Švec P (1982) Two new species of diving birds from the Lower Miocene of Czechoslovakia. *Cas Mineral Geol* 27:243-260

Švec P (1984) Further finds of grebe *Miobaptus walteri* in the Miocene of Bohemia. *Cas Mineral Geol* 29:167-170

Tambussi C, Acosta Hospitaleche C (2007) Antarctic birds (Neornithes) during the Cretaceous-Eocene times. *Rev Asoc Geol Argent* 62 (4):604-617

Tambussi CP (1995) The fossil Rheiformes from Argentina. *Cour Forsch Inst Senckenberg* 181:121-129

Tambussi CP (2011) Palaeoenvironmental and faunal inferences based on the avian fossil record of Patagonia and Pampa: what works and what does not. *Biol J Linn Soc* 103:458-474

Tambussi CP, Degrange FJ (2013) *South American and Antarctic Continental Cenozoic Birds: Paleobiogeographic affinities and disparities*. SpringerBriefs in Earth System Sciences. Springer, New York London

Tambussi CP, Noriega JI, Santillana S, Marenssi S (1995) Falconid bird from the middle Eocene La Meseta Formation, Seymour Island, West Antarctica. *J Vertebr Paleontol Abstr* 15 (55A)

Vickers-Rich PV (1991) The Mesozoic and Tertiary history of birds on the Australian plate. In: Vickers-Rich PV, Monaghan TM, Baird RF, Rich TH (eds) *Vertebrate palaeontology of Australasia*. Pioneer Design Studio and Monash University Publications Committee, Melbourne, pp 721-808

Waterhouse DM (2006) Parrots in a nutshell: The fossil record of Psittaciformes (Aves). *Hist Biol* 18 (2):223-234

Weidig I (2003) *Fossil birds from the Lower Eocene Green River Formation (USA)*. Ph.D Thesis. Johann Wolfgang Goethe Universität, Frankfurt

Wetmore A (1956) A fossil guan from the Oligocene of South Dakota. *Condor* 58 (3):234-235

Wijnker E, Olson SL (2009) A revision of the fossil genus *Miocepphus* and other Miocene Alcidae (Aves: Charadriiformes) of the Western North Atlantic Ocean. *J Syst Palaeontol* 7 (4):471-487

Worthy AJD, Tennyson C, Jones JA, McNamara JA, Douglas BJ (2007) Miocene waterfowl and other birds from central Otago, New Zealand. *J Syst Palaeontol* 5 (1):1-39

Worthy TH, Hand SJ, Archer M (2014) Phylogenetic relationships of the Australian Oligo-Miocene *Emuarius gidju* Casuariidae. *Integ Zool* 9:148-166

Worthy TH, Scanlon JD (2009) An Oligo-Miocene Magpie goose (Aves: Anseranatidae) from Riversleigh, Northwestern Queensland, Australia. *J Vertebr Paleontol* 29 (1):205-211

Worthy TH, Tennyson AJD, Scofield RP (2012) An early Miocene diversity of parrots (Aves,Strigopidae, Nestorinae) from New Zealand. *J Vertebr Paleontol* 31 (5):1102-1116

Worthy TH, Worthy JP, Tennyson AJD, Salisbury SW, Hand SJ, Scofield RP (2013) Miocene fossils show that kiwi (*Apteryx*, Apterygidae) are probably not phyletic dwarves. In: Göhlich UB, Kroh A (eds) *Paleornithological Research* 2013. Proceed. 8th Internat. Meeting Society of Avian Paleontology and Evolution. Society of Avian Paleontology and Evolution, Vienna, Austria., pp 63-80

Zelenkov N, Dyke GJ (2008) The fossil record and evolution of Mousebirds (Aves: Coliiformes). *Palaeontology* 51 (6):1403-1418

Appendix 3.8.3.

Table S3a. Areas definition for each node in Neornithes (1 - 0.5 - 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand. **1** y **2** (*italics*): Opisthocomiformes.

Node	Probability of combinations % (until 50%)	Defined areas
1	**SFTU**=38.12; **SFT**=18.48	S F T U
2	**ST**=15.35; S**FT**=9.49; N**ST**=8.58; **S**=8.31; N**ST**Z=7.72; **SFTU**=7.66	S T
3	**NSFEAU**=63.07	N S F E A U
1	**S**=84.30	S
2	**S**=100.00	S
4	**S**=100.00	S
5	**S**=100.00	S
6	**SFMI**=51.51	S F M I
7	**S**=100.00	S
8	**S**=100.00	S
9	**S**=100.00	S
10	**S**=9.59; N**S**=4.93; **SE**=4.54; **SF**=3.82; **SZ**=3.12; **SA**=3.06; N**SE**=3.05; **ST**=2.74; N**SF**=2.64; **SU**=2.46; **SFE**=2.45; N**SZ**=2.38; N**SA**=2.24; **SEZ**=2.20; N**SU**=2.09; **SEA**=2.08	S

Table S3b. Areas definition for each node in Neornithes (1 - 0.25 - 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand. **1** y **2** (*italics*): Opisthocomiformes.

Node	Probability of combinations % (until 50%)	Defined areas
1	**SFTU**=46.34; **SETU**=20.78	S F T U
2	**ST**=17.83; **S**=12.52; **SFTU**=9.98; **SFT**=9.97	S T
3	**NSFEAU**=61.29	N S F E A U
1	**S**=100.00	S
2	**S**=100.00	S
4	**S**=100.00	S
5	**S**=100.00	S
6	**SFMI**=49.03; **SFM**=17.67	S F M I
7	**S**=100.00	S
8	**S**=100.00	S
9	**S**=100.00	S
10	**S**=17.64; **SF**=7.09; N**S**=6.94; **SE**=6.93; **SZ**=6.44; **SA**=4.76; **SFZ**=3.95	S

Table S3c. Areas definition for each node in Neornithes (1 - 0.5 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand. **1** y **2** (*italics*): Opisthocomiformes.

Node	Probability of combinations % (until 50%)	Defined areas
1	**FT**=6.51; **FT**U=4.47; SFT=4.00; S**FT**U=3.37; **T**=2.95; **FT**UZ=2.69; F**ET**=2.22; S**FT**UZ=2.12; **FT**Z=1.71; **T**U=1.69; S**T**=1.50; **F**=1.28; S**T**U=1.18; S**FT**Z=1.08; **T**UZ=1.01; **FT**M=0.95; S**FE**T=0.93; NSE=0.85; SE=0.84; **FEAT**=0.83; SE**T**=0.81; S**F**=0.79; **FET**U=0.77; S**T**UZ=0.76; **F**U=0.74; E**T**=0.74; NSEA=0.65; **T**Z=0.62; S**FET**U=0.61; SE**T**U=0.60; S**F**U=0.56; NS**F**EA=0.56	T F
2	**T**UZ=1.77; **ST**UZ=1.39; **T**=1.26; **ST**=1.22; **NSFEAT**UZI=1.09; **S**=1.02; **NSFEATI**=1.01; **T**Z=1.00; **T**U=0.98; **NSFEAT**UZ=0.96; **NSFEAT**=0.93; **ST**Z=0.86; **ST**U=0.84; UZ=0.75; **NSFEAT**ZI=0.68; **NSFEAT**UI=0.66; **NSFEAT**Z=0.61; **NSFEAI**=0.61; **NSFEAT**U=0.60; **FT**UZ=0.59; **NFEAT**UZI=0.59; **NSEAT**UZI=0.57; **NSFEA**=0.56; **NSFEAT**UZMI=0.55; U=0.53; **NFEAT**UZ=0.52; **NSEAT**UZ=0.52; **NSEAI**=0.50; **SFT**UZ=0.50; Z=0.50; **NFEAI**=0.49; **NSFEAT**MI=0.49; **NSEA**=0.49; **NSEATI**=0.48; **NFEATI**=0.48; **NST**UZ=0.47; **NSFEAT**UZM=0.47; **FT**=0.46; **NSEAT**=0.46; **SFT**=0.46; **NFEA**=0.46; **NFEAT**=0.45; **NSFEAT**M=0.44; **NST**=0.43; **NS**=0.43; **NSFAT**UZI=0.37; **FT**Z=0.36; **NFEAT**ZI=0.35; **FT**U=0.35; **NSEAT**ZI=0.35; **NEAI**=0.34; **NSFA**TI=0.34; **NFEAT**UI=0.34; **NSEAT**UI=0.34; **NSFAT**UZ=0.34; **NSFEAT**ZMI=0.34; **SFEAT**UZI=0.34; **NSFET**UZ=0.33; **NSFEAT**UMI=0.33; **NSFAT**=0.33; **NSFET**=0.33; **NEA**=0.32; **NSEAT**Z=0.32; **SFT**Z=0.32; **NFEAT**Z=0.32; **NSEA**TU=0.31; **SFT**U=0.31; **SFEAT**UZ=0.31; **NFEAT**U=0.31; SUZ=0.31; **NST**Z=0.31; **SFEATI**=0.30; **NEAT**UZI=0.30; **NSFEAT**ZM=0.30; **NFEAT**UZMI=0.29; **NSAT**UZI=0.29; **SFEAT**=0.29; **NSFEAT**UM=0.29; **NST**U=0.29; **NSAT**UZ=0.29; **FEAT**UZI=0.28; **NEAT**UZ=0.27; **FEAT**UZ=0.27; **NSFEA**MI=0.27; **NSA**=0.27; **NSET**UZ=0.26; **NSAT**=0.26; **NSAI**=0.26; **NFEAT**UZM=0.25; **NSFT**UZ=0.25; **NSATI**=0.25; **NSFT**=0.24; **NSE**=0.24; **NSFEA**M=0.24; **NSET**=0.24; **NFEAT**MI=0.23; **NSFAT**ZI=0.23; **SFET**UZ=0.23; FETUZ=0.22; NSFATUI=0.22; SZ=0.22; **FEAT**=0.22; **FEATI**=0.22; **FTUZ**M=0.22; **NSFAT**Z=0.22; **SFET**=0.22; SU=0.21; **NSFET**Z=0.21; **NSFAT**U=0.21; **SFEAT**ZI=0.21;	N S F E A T

	NSFEAUZI=0.21; **NSFET**U=0.21; **NFEAT**M=0.21; **NFEA**MI=0.20; **SFEAT**UI=0.20; **SFT**UZM=0.20; **T**UZM=0.20; **SFEAT**Z=0.20; **NFAT**UZI=0.20	
3	**NSFEATU**=3.98; **NSFEATUZ**=3.08; **NSFEATU**I=2.32; **NSFEATUZ**I=1.79; **NSFEAT**=1.48; **NFEATUZ**=1.46; **NFEATU**=1.41; **NSFEAU**=1.37; **NSFEATZ**=1.28; **NSEATU**=1.18; **NSFETU**=1.17; **NFEATZ**=1.14; **NSFETUZ**=0.98; **SFEATU**=0.97; **NSEATUZ**=0.97; **NSFEAUZ**=0.94; **NSFATU**=0.94; **NSFEATU**M=0.89; **NSFEAT**I=0.84; **NFEATUZ**I=0.82; **NFEATU**I=0.80; **NSFEAU**I=0.78; **NFEAZ**=0.74; **SFEATUZ**=0.73; **NSFATUZ**=0.73; **NFEAT**=0.73; **NSFEATUZ**M=0.70; **NSFEATZ**I=0.70; **NFEAU**=0.68; **NSEATU**I=0.67; **NFEAU**Z=0.66; **NFEATZ**I=0.59; **NSEATUZ**I=0.55; **SFEATU**I=0.55; **NSFEAUZ**I=0.54; **NSFATU**I=0.53; **NSFEATU**MI=0.53; **NSFETZ**=0.53; **NFETUZ**=0.52; **NFETZ**=0.52; **NSFET**=0.47; **NSFEAZ**=0.46; **SFETU**=0.46; **FEATUZ**=0.45; **NEATUZ**=0.45; **NSFTU**=0.44; **NSETU**=0.42; **NFETU**=0.42; **SFEATUZ**I=0.42; **FEATU**=0.42; **NSFEATUZ**MI=0.42; **NSFATUZ**I=0.41; **NSEATZ**=0.40; **NFEAT**I=0.39; **NSEAU**=0.39; **NEATU**=0.39; **NSETUZ**=0.38; **NFEAU**I=0.38; **NSFTUZ**=0.38; **NSEAT**=0.38; **SFETUZ**=0.37; **FEATZ**=0.37; **NSFEU**=0.37	N S F E A T U Z
1	**NEA**=2.94; **NSFEA**=2.27; **S**=2.04; **NFEA**=1.93; **NEA**I=1.71; **NSEA**=1.64; **NA**=1.54; **NSFEA**T=1.52; **NSFEA**I=1.35; **NS**=1.26; **EA**=1.23; **N**=1.23; **NFEA**I=1.18; **ST**=1.00; **NSA**=0.98; **NA**I=0.98; **NE**=0.98; **NSFEA**TI=0.97; **FEA**=0.92; **NSEA**I=0.90; T=0.81; **NSF**A=0.80; **EA**I=0.80; A=0.80; **SF**T=0.79; **A**I=0.77; **SF**=0.76; **E**=0.76; **NSFEA**MI=0.70; **NSFEA**M=0.69; TUZ=0.67; **SFEA**=0.66; **NSE**=0.66; **NSFE**=0.62; **NSFEA**TMI=0.58; **NFEA**T=0.58; **NFA**=0.57; **FEA**I=0.56; **NSFA**T=0.55; TU=0.55; **NSFEA**TM=0.55; **NSEA**T=0.54; **NSFEA**TUZI=0.52; I=0.51; **NFEA**MI=0.50; **SFEA**T=0.49; **NFEA**M=0.49; **NSA**I=0.49; **NSFEA**TU=0.48; **NSF**=0.45; **NSFA**I=0.45; **NSFEA**TUZ=0.45; **NSFE**T=0.44; **NSFEA**TZI=0.43; **NFE**=0.42; TZ=0.42; **NS**T=0.41; **NSFEA**TZ=0.41; U=0.40; **FE**=0.40; **S**TU=0.40; **F**=0.40	N S F E A
2	**NEA**=4.73; **NSFEA**=4.27; **NFEA**=3.89; **NEA**I=3.29; **NSFEA**T=3.24; **NSFEA**I=2.93; **NFEA**I=2.72; **NSEA**=2.55; **NSFEA**TI=2.30; **NA**=2.16; **EA**=2.03; **FEA**=1.85; **NSFEA**MI=1.74; **NSEA**I=1.67; **NA**I=1.64; S=1.58; **NSFEA**M=1.57; **NSFEA**TMI=1.53; **EA**I=1.53; **NFEA**MI=1.43;	N F E A

	NE=1.41;	
4	**NEA**=5.65; **NFEA**=4.55; **NSFEA**=4.31; **NEAI**=3.54; **NSFEAT**=3.01; **NFEAI**=2.81; **EA**=2.67; **NA**=2.62; **NSEA**=2.57; **NSFEAI**=2.53; **FEA**=2.43; **NAI**=1.87; **EAI**=1.84; **NSFEATI**=1.79; **AI**=1.75; **NE**=1.68; S=1.65; **A**=1.64; **E**=1.62; **N**=1.58	N E A
5	F=14.35; A=11.90; E=11.11; N=10.54	Indet.
6	**NSFEAI**M=5.27; **NSFEAI**=5.02; **NSFEAI**TM=2.58; **NSFA**M**I**=2.28; **NSEAI**=2.24; **NSFEAT**I=2.24; **NSFAI**=2.19; **NSFEA**=1.99; **NSFEA**M=1.91; **NFEAI**=1.87; **NFEA**M**I**=1.83; **NSEA**M**I**=1.32; **NSEA**=1.26; **SFEA**M**I**=1.21; **SFEAI**=1.18; **NSFA**TM**I**=1.15; **NSAI**=1.09; **NSFE**M**I**=1.04; **NSFA**T**I**=1.01; **NSFEI**=0.99; **NEAI**=0.92; **NSFEA**TM=0.92; **NSFEA**T=0.87; **NFEA**=0.80; **NSFMI**=0.80; **NSFA**=0.78; **NSFA**M=0.76; **NSFI**=0.75; **SFEA**TM**I**=0.73; **NFEA**M=0.71; **SFEA**TI=0.65; **NFEA**TM**I**=0.64; **NFAI**=0.62; NSAMI=0.61; **NSA**=0.59; **NFA**M**I**=0.59; **NSEA**T**I**=0.58	N S F E A I
7	F=13.70; A=11.45; E=10.50; N=9.93; S=8.84	Indet.
8	NEA=5.83; F=5.25; E=4.51; EA=4.49; NA=4.32; N=4.27; S=4.19; A=3.95; NFEA=3.27; FEA=2.99; T=2.54; NE=2.45; M=2.43	Indet.
9	**NEA**=4.28; **NFEA**=3.30; **NSFEA**=3.00; **NSFEA**TMI=2.64; **NSFEA**TUZMI=2.60; **EA**=2.14; **NA**=2.06; **NSFEA**T=2.06; **FEA**=1.92; **NSFEA**TM=1.88; **NSEA**=1.82; **NSFEA**TZMI=1.77; **NSFEA**MI=1.58; **NSFEA**TUMI=1.55; **E**=1.55; **F**=1.55; S=1.55; **N**=1.50; NSFEAM=1.46; **NE**=1.40; **NSFEA**TI=1.39; **NFEA**MI=1.36; **NSFEA**TUZM=1.34; **NFEAI**=1.29; **NFEA**M=1.28; FM=1.24; **NSFEAI**=1.23; **A**=1.21; **SF**T=1.20; M=1.19	N S F E A
10	**NFEAT**=0.12; **NFEA**=0.12; **FEAT**=0.12; **NFAT**=0.12; **NEAT**=0.12; **NSFEAT**=0.12; **NSFEA**=0.12; **SFEAT**=0.11; **NSEAT**=0.11; **NSFAT**=0.11; **NFEATZ**=0.11; **NFET**=0.11; **NFEATI**=0.11; **SFEA**=0.11; **NFEAZ**=0.11; **NFA**=0.11; **NSFA**=0.11; **FEA**=0.11; **NFEAI**=0.11; **NSFEATI**=0.11; **NSFEATZ**=0.11; **NSEA**=0.11; **NSFET**=0.11; **EAT**=0.11; **SEAT**=0.11; **FEATZ**=0.11; **NEATZ**=0.11; **NFATZ**=0.11; **NSFEAZ**=0.11; **NEATI**=0.11; **NSFEAI**=0.11; **FAT**=0.11; **NFATI**=0.11; **FEATI**=0.11; **NFEATU**=0.11; **NAT**=0.11; **SFAT**=0.11; **NSAT**=0.11; **SFEATZ**=0.11; **NSEATZ**=0.11; **NSEATI**=0.11; **SFEATI**=0.11; **NEA**=0.11; **NFAZ**=0.11; **FEAZ**=0.11; **NSFATZ**=0.11; **NSFEATU**=0.11; **NSFATI**=0.11;	N S F E A T

NFEATM=0.11; **NFEA**U=0.11; **NFEAT**ZI=0.11; **NEA**Z=0.11;
NSFE=0.11; **NFA**I=0.11; **SFEA**Z=0.11; **NFET**Z=0.11;
NFETI=0.11; **NSFEA**U=0.11; **NSEA**Z=0.11; **SFEA**I=0.11;
NSFAZ=0.11; **NSFEAT**M=0.11; **NFEA**ZI=0.11; **FEAT**U=0.11;
NSEAI=0.11; **NSFEAT**ZI=0.11; **FEA**I=0.11; **NEA**I=0.11;
NSFAI=0.11; **NFAT**U=0.11; **NEAT**U=0.11; **NFE**=0.11;
EATZ=0.11; **NSFET**Z=0.11; **NSFEA**ZI=0.11; **NSFET**I=0.11;
SFEATU=0.11; **NFEAT**UZ=0.11; **NAT**Z=0.11; **NSEAT**U=0.11;
NFEAM=0.11; **SEAT**Z=0.11; **NFEAT**UI=0.11; **NSET**=0.11;
NEATZI=0.11; **EAT**I=0.11; **NAT**I=0.11; **SEAT**I=0.11;
NSFATU=0.11; **NSFEA**M=0.11; **FEAT**ZI=0.11; **NFAT**ZI=0.11;
NFEZ=0.11; **SFET**=0.11; **FATZ**=0.11; **NSFEAT**UZ=0.11;
NSATZ=0.11; **NEAT**M=0.11; **NSAT**I=0.11; **NSFEAT**UI=0.11;
NSEATZI=0.11; **NFAT**M=0.11; **SFEAT**ZI=0.11; **FEAT**M=0.11;
SFATZ=0.11; **NE**T=0.11; **NFEAT**ZM=0.11; **FAT**I=0.11;
NSFT=0.11; **NFEAT**MI=0.11; **NSFE**Z=0.11; **NSFAT**ZI=0.11;
NFEAUZ=0.11; **SFAT**I=0.11; **NSEAT**M=0.11; **SFEAT**M=0.11;
NFT=0.11; **FET**=0.11; **NFEA**UI=0.11; **NSFE**I=0.11; **NFE**I=0.11;
SFEAU=0.11; **NFET**U=0.11; **NSFAT**M=0.11; **SEA**=0.11;
NSFEATMI=0.11; **SFA**=0.11; **NSFEAT**ZM=0.11;
NSFEAUZ=0.11; **NSFEA**UI=0.11; **NSFA**U=0.11; **NFA**ZI=0.11;
NFAU=0.11; **NSEA**U=0.11; **NEA**ZI=0.11; **FEA**U=0.11;
NSFETU=0.11; **FEA**ZI=0.11; **SFEA**ZI=0.11; **NSEA**ZI=0.11;
NFETZI=0.11; **NEAT**UZ=0.11; **FEAT**UZ=0.11; **NSFA**ZI=0.11;
NEATUI=0.11; **NFAT**UZ=0.11; **SEA**Z=0.11; **NET**Z=0.11;
FEATUI=0.11; **NFEAT**UZI=0.11; **NFEA**ZM=0.11;
NFATUI=0.11; **SFEAT**UZ=0.11; **NSEAT**UZ=0.11;
NSFETZI=0.11; **NSEAT**UI=0.11; **NSFEA**ZM=0.11;
NSFEAMI=0.11; **SFEAT**UI=0.11; **NFEA**MI=0.11; **SEAT**U=0.11;
NSETZ=0.11; **NSFAT**UZ=0.11; **NSET**I=0.11; **NSFEAT**UZI=0.11;
NEAU=0.11; **NET**I=0.11; **NFEAT**UM=0.11; **NSFAT**UI=0.11;
NFETM=0.11; **NSA**=0.11; **SEAT**ZI=0.11; **SEA**I=0.11;
EATZI=0.11; **NSFET**M=0.11; **NSFEAT**UM=0.11; **SFA**Z=0.11;
SFEAM=0.11; **NSA**Z=0.11; **EAT**U=0.11; **SFET**Z=0.11;
NFEATZMI=0.11; **NEAT**ZM=0.11; **NSAT**U=0.11; **FET**Z=0.11;
NATZI=0.11; **NSFA**M=0.11; **NSEA**M=0.11; **NFT**Z=0.11;
NEATMI=0.11; **FEAT**ZM=0.11; **SFAT**U=0.11; **SFET**I=0.11;
NSEATMI=0.11; **NSAT**ZI=0.11; **NSA**I=0.11; **NSEAT**ZM=0.11;
NFATZM=0.11; **NSFEAT**ZMI=0.11; **SFEAT**ZM=0.11;
NFEAUZI=0.11; **SFEAT**MI=0.11; **NSFT**Z=0.11; **NFAT**MI=0.11;
FEATMI=0.11; **NAT**U=0.11; **NFT**I=0.11; **NSFEA**UZI=0.11;
SFAI=0.11; **NSFAT**ZM=0.11; **NSFT**I=0.11; **FAT**U=0.11;

NSFATMI=0.11; **NSFE**U=0.11; **SFEA**UZ=0.11; **NSFE**ZI=0.11; **NFE**ZI=0.11; **SFAT**ZI=0.11; **NFA**M=0.11; **NFET**UZ=0.11; **FAT**ZI=0.11; **SAT**=0.11; **NSEA**UZ=0.11; **SFEA**UI=0.11; **FET**I=0.11; **NFET**UI=0.11; **NSFA**UZ=0.11; **SEAT**M=0.11; **NSEA**UI=0.11; **FEA**UZ=0.11; **NSFET**UZ=0.11; **NFA**UZ=0.11; **NSFA**UI=0.11; **NSFET**UI=0.11; **FA**=0.11; **NEA**UZ=0.10; **NFA**UI=0.10; **NEAT**UZI=0.10; **NSFEA**UM=0.10; **FEA**UI=0.10; **NSEAT**UZI=0.10; **FEAT**UZI=0.10; **NFE**U=0.10; **NEA**M=0.10; **NSFEA**ZMI=0.10; **SFEAT**UZI=0.10; **NEA**UI=0.10; **NSAT**M=0.10; **NFEA**UM=0.10; **NFEA**ZMI=0.10; **NFAT**UZI=0.10; **NFEAT**UZM=0.10; **FEA**M=0.10; **NSFEAT**UZM=0.10; **NFEAT**UMI=0.10; **NSFAT**UZI=0.10; **NSFEAT**UMI=0.10; **SEAT**UZ=0.10; **SEA**ZI=0.10; **SFAT**M=0.10; **NAT**M=0.10; **SEAT**UI=0.10; **NSET**ZI=0.10; **SFEA**ZM=0.10; **NFET**ZM=0.10; **NSFET**ZM=0.10; **EAT**M=0.10; **NSEA**ZM=0.10; **NSFET**MI=0.10; **NSEAT**UM=0.10; **SFEAT**UM=0.10; **NET**ZI=0.10; **NSEA**MI=0.10; **NFET**MI=0.10; **SFEA**MI=0.10; **FA**Z=0.10; **NSET**U=0.10; **NSFA**ZM=0.10; **NSEAT**ZMI=0.10; **NEAT**UM=0.10; **NEAT**ZMI=0.10; **EAT**UZ=0.10; **NSFE**M=0.10; **SFEAT**ZMI=0.10; **NSE**Z=0.10; **NSAT**UZ=0.10; **NSFA**MI=0.10; **FEAT**UM=0.10; **SAT**Z=0.10; **NSFAT**UM=0.10; **NSA**ZI=0.10; **NSAT**UI=0.10; **NFAT**UM=0.10; **EAT**UI=0.10; **FEAT**ZMI=0.10; **SAT**I=0.10; **NSFAT**ZMI=0.10; **NFAT**ZMI=0.10; **SFAT**UZ=0.10; **SFET**ZI=0.10; **NSFE**UZ=0.10; **NFA**ZM=0.10; **SFA**ZI=0.10; **SFET**U=0.10; **NAT**UZ=0.10; **NAT**UI=0.10; **SFE**Z=0.10; **SFAT**UI=0.10; **NEA**ZM=0.10; **FEA**ZM=0.10; **SFE**=0.10; **NSFE**UI=0.10; **SFEA**UZI=0.10; **NSEA**UZI=0.10; **SEA**U=0.10; **NSFT**ZI=0.10; **NSFET**UZI=0.10; **FAT**M=0.10; **NFET**UZI=0.10; **NSFEA**UZM=0.10; **NSE**I=0.10; **SEAT**ZM=0.10; **NSFA**UZI=0.10; **FAT**UZ=0.10; **NFE**UZ=0.10; **NSFEA**UMI=0.10; **NFA**MI=0.10; **NSFT**U=0.10; **NFT**ZI=0.10; **SEAT**MI=0.10; **NSFEAT**UZMI=0.10; **FET**ZI=0.10; **NFEA**UZM=0.10; **NFEAT**UZMI=0.10; **NEA**MI=0.10; **EA**Z=0.10; **NET**U=0.10; **FAT**UI=0.10; **NSF**Z=0.10; **NEA**UZI=0.10; **FEA**UZI=0.10; **NFA**UZI=0.10; **SFA**U=0.10; **NFE**UI=0.10; **NFEA**UMI=0.10; **NA**ZI=0.10; EA=0.10; **FEA**MI=0.10; **EA**ZI=0.10; **NSAT**ZM=0.10; **AT**=0.10; **NSAT**MI=0.10; **NSET**M=0.10; **EA**I=0.10; **NFE**M=0.10; **SFE**I=0.10; **NSF**=0.10; **FA**I=0.10; **NSEAT**UZM=0.10; **NSE**=0.10; **NSF**I=0.10; **FET**U=0.10; **NA**Z=0.10; **SFEAT**UZM=0.10; **EAT**ZM=0.10; **SEAT**UZI=0.10; **NSFET**ZMI=0.10; **NFT**U=0.10; **NSEAT**UMI=0.10; **NSFET**UM=0.10; **SFAT**ZM=0.10; **NSA**U=0.10; **NSEA**ZMI=0.10; **SFEA**ZMI=0.10;

SFEATUMI=0.10; **NSFE**ZM=0.10; **NEAT**UZM=0.10;
NSFATUZM=0.10; **NFET**ZMI=0.10; **NAT**ZM=0.10;
NSETUZ=0.10; **SFAT**MI=0.10; **NSET**UI=0.10; **EAT**MI=0.10;
NEATUMI=0.10; **NSF**EMI=0.10; **FEAT**UZM=0.10;
NSFAZMI=0.10; **NSFAT**UMI=0.10; **SFEA**UM=0.10;
NFETUM=0.10; **NFAT**UZM=0.10; **NAT**MI=0.10;
NSATUZI=0.10; **FA**ZI=0.10; **SEA**UZ=0.10; **FEAT**UMI=0.10;
NSEAUM=0.10; **NA**=0.10; **SFET**M=0.10; **NFAT**UMI=0.10;
EATUZI=0.10; **NSE**ZI=0.10; **NSFA**UM=0.10;
NSFEAUZMI=0.10; **SEA**UI=0.10; **SAT**ZI=0.10; **NSFE**UZI=0.10;
SFETUZ=0.10; **SFAT**UZI=0.10; **NEA**ZMI=0.10; **NSFT**M=0.10;
NATUZI=0.10; **FAT**ZM=0.10; **NFA**ZMI=0.10; **NET**M=0.10;
SFETUI=0.10; **NFE**ZM=0.10; **NET**UZ=0.10; **FEA**ZMI=0.10;
NFEAUZMI=0.10; **NET**UI=0.10; **NA**I=0.10; **SEAT**ZMI=0.10;
NSFTUZ=0.10; **SFA**UZ=0.10; **SFE**ZI=0.10; **NSA**UZ=0.10;
NSFTUI=0.10; **NFE**UZI=0.10; **NSA**UI=0.10; **FAT**MI=0.10;
SET=0.10; **NSEAT**UZMI=0.10; **SEAT**UM=0.10; **SET**Z=0.10;
SFAUI=0.10; **FAT**UZI=0.10; **NSET**ZM=0.10; **NSAT**ZMI=0.10;
SFEATUZMI=0.10; **NFE**MI=0.10; **SEA**M=0.10; **NSET**MI=0.10;
NSFETUZM=0.10; **NSF**ZI=0.10; ATZ=0.10; **NFA**UM=0.10;
NSFETUMI=0.10; **NSFAT**UZMI=0.10; **NEAT**UZMI=0.10;
FETUZ=0.10; **FEA**UM=0.10; **NFT**UZ=0.10; **SET**I=0.10;
SFEAUZM=0.10; **NSA**M=0.10; **NSFE**ZMI=0.10; **NFT**M=0.10;
NSEAUZM=0.10; **SFAT**ZMI=0.10; **NSET**UZI=0.10;
NEAUM=0.10; **NSAT**UM=0.10; **EAT**ZMI=0.10;
NFETUZM=0.10; **NFT**UI=0.10; **FEAT**UZMI=0.10; **FET**UI=0.10;
ATI=0.10; **NFAT**UZMI=0.10; **NSEA**UMI=0.10; **SFEA**UMI=0.10;
SATU=0.10; **NSFA**UZM=0.10; **NE**ZI=0.10

Table S3d. Areas definition for each node in Neornithes (1 - 0.1 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand. **1** y **2** (*italics*): Opisthocomiformes.

Node	Probability of combinations % (until 50%)	Defined areas
1	**SFTU**=40.09; **SFT**=21.12	S F T U
2	**ST**=20.11; SF**T**=12.96; **SFTU**=8.75; **STZ**=8.09; **T**=6.59	S T
3	**SFTU**=15.41; **SFETU**=12.58; **SFEATU**=12.26; N**SFEATU**=7.39; **SFEATUI**=3.59	S F E T U
1	**S**=41.64; **SF**=38.32	S F
2	**S**=100.00	S
4	**S**=80.11	S
5	**S**=81.50	S
6	**NSFEAMI**=14.66; **NSFAMI**=14.37; **SFAMI**=10.04; **NSFMI**=8.53 **SFEAMI**=7.52	N S F A M I
7	**S**=71.55	S
8	**S**=54.09	S
9	**ST**=37.12; **S**=31.63	S T
10	**T**=1.58; **ST**=1.18; **STU**=0.99; **STZ**=0.94; **TU**=0.86; **TZ**=0.82;**STUZ**=0.82; **SFT**=0.74; **SFTU**=0.73; **SFTZ**=0.69; F**T**=0.68; **TUZ**=0.66; **SFTUZ**=0.63; **STU**M=0.62; F**TU**=0.62; F**TZ**=0.59; **STZ**M=0.58; **STUZ**M=0.57; **ST**M=0.56; **S**=0.56; F**TUZ**=0.55; **STU**I=0.53; **STZ**I=0.52; **ST**I=0.50; **SFTU**M=0.50; **STUZ**I=0.49; **S**U=0.48; **SFTZ**M=0.47; **SFTUZ**M=0.47; **SZ**=0.47; **SFT**M=0.45; **TU**M=0.45; **TUZ**M=0.45; **SUZ**=0.44; N**STU**=0.44; N**STZ**=0.44; **T**M=0.44; **TZ**M=0.43; **SFTU**I=0.43; **SFTZ**I=0.43; **SETU**=0.43; **SETZ**=0.43; **SFTUZ**I=0.42; N**STUZ**=0.41; **T**I=0.41; **TZ**I=0.41; **SATU**=0.40; **TU**I=0.40; **SATZ**=0.40; N**ST**=0.40; **SETUZ**=0.40; F**TU**M=0.40; **SFT**I=0.40; **SFU**=0.40; **TUZ**I=0.40; **SFUZ**=0.39; F**TUZ**M=0.39; F**TZ**M=0.39; **SATUZ**=0.39; **SFZ**=0.38; **SET**=0.38; N**SFTU**=0.38; **STU**MI=0.37; **STUZ**MI=0.37; N**SFTZ**=0.37; **SFETU**=0.37; **STZ**MI=0.37; **SFETZ**=0.37; N**SFTUZ**=0.36; **SAT**=0.36; F**TU**I=0.36; **SFETUZ**=0.36; F**TZ**I=0.36; **SFATU**=0.35; **SFATZ**=0.35; F**TUZ**I=0.35; F**T**M=0.35; **SFATUZ**=0.34; E**TU**=0.34; A**TZ**=0.34; **SF**=0.34; N**SFT**=0.34; N**TU**=0.33; N**TUZ**=0.33; **SFET**=0.33; A**TU**=0.33; **SFTUZ**MI=0.33; N**T**=0.33; **SFTU**MI=0.33; **SFTZ**MI=0.32; E**TUZ**=0.32; F**T**I=0.32; **ST**MI=0.32; E**TZ**=0.32; **SFAT**=0.32; N**STZ**I=0.31; N**TZ**=0.31; N**SATZ**=0.31; N**SATUZ**=0.31; N**STUZ**I=0.31; A**TUZ**=0.31; N**SATU**=0.31; NF**TZ**=0.31; N**SETZ**=0.31; N**STU**I=0.31; **SEATZ**=0.31; N**SETUZ**=0.31; NF**TU**=0.31; **SETZ**I=0.31; **SEATUZ**=0.31; N**SETU**=0.30	S F T U Z

Appendix 3.8.4.

Table S4a. Areas definition for each node in Paleognathae (1 - 0.5 - 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**F**=50.45	F
2	**F**=42.76; **FE**=30.68	F E
3	**Z**=100	Z
4	**SZ**=100	S Z
5	**NSZ**=36.94; **SEZ**=36.03	S Z N E
6	**U**=100.00	U
7	**UZ**=100.00	U Z
8	**NSZ**=24.46; **SEZ**=24.37; **NSUZ**=13.42	S Z N
9	**NSZ**=27.01; **SEZ**=26.02	S Z N E
10	**NSFZ**=19.35; **SFEZ**=18.16; **NSFUZ**=10.53; **SFEUZ**=9.71	S Z F N E

Table S4b. Areas definition for each node in Paleognathae (1 - 0.25 - 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**F**=50.52	F
2	**F**=47.16; **FE**=25.56	F E
3	**Z**=100	Z
4	**SZ**=100	S Z
5	N**SZ**=23.90; **SEZ**=23.29; **Z**=10.00	S Z
6	**U**=100	U
7	**UZ**=100	U Z
8	**NSZ**=17.17; **SEZ**=16.97; **NSUZ**=9.44; **SEUZ**=9.18	S Z N E
9	**NSZ**=22.25; **SEZ**=21.56; **NSUZ**=12.53	S Z N
10	**NSFZ**=16.08; **SFEZ**=15.36; **NSFUZ**=9.24; **SFEUZ**=8.61; **SFZ**= 7.48	S F Z N

T**able S4c.** Areas definition for each node in Paleognathae (1 - 0.5 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**F**=43.02; **FE**=35.38	F E
2	**F**=37.21; **FE**=33.25	F E
3	**Z**=100.00	Z
4	**SZ**=100.00	S Z
5	**NSZ**=51.53	N S Z
6	**U**=100.00	U
7	**UZ**=100.00	U Z
8	**NSZ**=31.42; **SEZ**=30.43	S Z N E
9	**NSZ**=32.20; **SEZ**=29.92	S Z N E
10	**NSFZ**=22.60; **SFEZ**=20.23; **NSFUZ**=11.56	S F Z N

T**able S4d.** Areas definition for each node in Paleognathae (1 - 0.1 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**F**=74.25	F
2	**F**=58.37	F
3	**Z**=100	Z
4	**SZ**=100	S Z
5	**NSZ**=43.12; **SEZ**=36.74	S Z N E
6	**U**=100	U
7	**UZ**=100	U Z
8	**NSZ**=26.01; **SEZ**=22.52; **NSUZ**=14.82	S Z N
9	**NSZ**=26.47; **SEZ**=22.24; **NSUZ**=14.90	S Z N
10	**NSFZ**=23.98; **SFEZ**=19.85; **NSFUZ**=13.67	S F Z N

Appendix 3.8.5.
Table S5a. Areas definition for each node in Galloanseres (1 - 0.5 – 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**E**=25.00; N=23.67; A=10.44	E
2	**S**=100.00	S
3	**U**=28.60; **S**=26.86	U S
4	**SU**=100.00	S U
5	**S**=86.56	S
6	**S**=100.00	S
7	**S**=40.90; **SU**=26.63	S U
8	**S**=40.35; **SU**=27.43	S U
9	**SU**=41.30; **SEU**=15.64	S U
10	**N**=100.00	N
11	**F**=43.75; **A**=39.39	F A
12	**NFEAI**M=15.54; **NFEAI**=15.02; **E**=13.03; **NFEA**=12.27	E N F A I
13	**NFE**=11.59; **NFEA**=11.38; **NE**=9.54; **NEA**=9.49; **N**=9.06	N E
14	**NFEA**=17.54; **NEA**=15.28; **NFE**=11.83; **NFEAI**=7.68	N E A F
15	**NFEA**=21.62; **NEA**=19.08; **NFE**=15.14	N E A F
16	**NFEA**=35.89; **NEA**=27.51	N E A F
17	**E**=100.00	E
18	**E**=100.00	E
19	**E**=100.00	E
20	**E**=100.00	E
21	**SEU**=61.84	S E U
22	**NSEU**=29.29; **SEU**=21.66; **SEAU**=14.42	S E U N

Table S5b. Areas definition for each node in Galloanseres (1 - 0.25 – 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	E=24.18; **N**=23.31; **N**A=13.09	N
2	**S**=100.00	S
3	**U**=38.70; S=22.87	U
4	**SU**=100.00	S U
5	**S**=83.17	S
6	**S**=87.79	S
7	**S**=36.31; **SU**=28.62	S U
8	**S**=33.32; **SU**=28.28	S U
9	**SU**=39.60; **S**T**U**=15.83	S U
10	**N**=100.00	N
11	**F**=38.07; **A**=34.42	F A
12	**NFEAI**M=17.27; **NFEAI**=16.30; **NEA**=12.53; **NFEA**=11.94	N E A F I
13	**N**=12.52; **N**F**E**A=10.97; **NE**=10.37; **NE**A=9.65; **N**F**E**=9.26	N E
14	**NEA**=15.53; **NFEA**=14.91; **NFE**=9.03; **NFEAI**=8.17; **NFEAI**M=7.28	N E A F
15	**NEA**=18.67; **NFEA**=18.46; **NFE**=11.81; **NFEAI**=8.47	N E A F
16	**NFEA**=27.70; **NEA**=27.15; **NFEAI**=10.29	N E A F
17	**E**=100.00	E
18	**E**=100.00	E
19	**E**=100.00	E
20	**E**=100.00	E
21	**SEU**=53.08	S E U
22	**NSEU**=25.56; **SEU**=18.90; **SEAU**=15.29	S E U N

Table S5c. Areas definition for each node in Galloanseres (1 - 0.5 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**N**=27.92; **E**=17.77; **NE**=11.52	N E
2	**S**=100.00	S
3	**U**=100.00	U
4	**SU**=100.00	S U
5	**SU**=87.42	S U
6	**SU**=57.43	S U
7	**SU**=63.47	S U
8	**SU**=62.30	S U
9	**SU**=64.05	S U
10	**N**=100.00	N
11	**F**=35.26; **A**=35.09	F A
12	**E**=27.64; **E**A=13.74; N**E**A=10.72	E
13	**E**=27.34; A=17.02; NF**E**=12.35	E
14	**A**=13.34; **E**=11.59; NF**E**=10.65; NF**EA**=9.93; **EA**=8.42	A E
15	**NA**=17.95; **NEA**=16.82; **N**F**EA**=16.45	N E A
16	**NFEA**=27.14; **NEA**=26.16	N E A F
17	**E**=67.26	E
18	**E**=69.15	E
19	**E**=68.83	E
20	**E**=68.76	E
21	**SEU**=34.54; N**SU**=18.67	S U E
22	**NSEU**=19.05; **SEU**=13.57; **NSETU**=12.49; **NSU**=9.92	S E U N

Table S5d. Areas definition for each node in Galloanseres (1 - 0.1 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**N**=18.08; **NEA**=13.34; **NA**=12.58; **E**=11.79	N E A
2	**S**=100.00	S
3	**U**=100.00	U
4	**SU**=100.00	S U
5	**SU**=100.00	S U
6	**SU**=55.11	S U
7	**SU**=55.16	S U
8	**SU**=55.13	S U
9	**SU**=56.10	S U
10	**N**=100.00	N
11	**E**=34.87; **A**=26.30	E A
12	**E**=30.25; **EA**=18.38; N**EA**=17.35	E A
13	**E**=32.24; A=23.37	E
14	**E**=19.73; **A**=16.74; **EA**=10.98; N**EA**=8.64	E A
15	**NE**=19.75; **NEA**=18.81; **NA**=17.42	N E A
16	**NEA**=33.00; N**FEA**=14.35; **NA**=12.57	N E A
17	**E**=54.03	E
18	**E**=56.56	E
19	**E**=56.71	E
20	**E**=52.71	E
21	**SEU**=26.54; **SETU**=18.41; N**SU**=13.54	S U E
22	**NSEU=11.81; NSETU=11.08; SEAU=8.68; SEU=8.54; SEATU=7.61; NSAU=6.80**	S E U N

Appendix 3.8.6.
Table S6a. Areas definition for each node in Columbea (1 - 0.5 - 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**E**=21.67; **EM**=12.46; F**EM**=9.81; **FE**=8.30	E M
2	**EM**=24.75; F**EM**=19.32; **M**=11.85	E M
3	**SU**=100.00	S U
4	**SUM**=36.34; S**EU**=22.61	S U
5	**U**=15.86; S**U**=10.42; I**U**=9.51; A**U**=9.21; F**U**=8.45	U
6	**U**=46.23; **E**=25.66	U E
7	**U**=45.51: **E**=32.01	U E
8	**U**=60.80	U
9	**U**=46.76; **E**=30.21	U E
10	**SEU**=18.85; **SU**M=16.52; S**FU**=10.63; **SEUM**=10.49	S U E M

Table S6b. Areas definition for each node in Columbea (1 - 0.25-0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**E**=29.52; **EM**=18.83; **M**=10.18	E M
2	**EM**=34.46; **M**=14.44; F**EM**=11.92	E M
3	**SU**=100	S U
4	**SUM**=36.74; **SEU**=23.64	S U
5	**U**=19.84; S**U**=14.45; F**U**=11.72; I**U**=10.91	U
6	**U**=55.81	U
7	**U**=51.16	U
8	**U**=74.34	U
9	**U**=52.33	U
10	**SEU**=23.00; **SUM**=20.09; **SEUM**=11.86	S U E M

Table S6c. Areas definition for each node in Columbea (1 - 0.5-0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**F**=32.46; **F**M=13.46; **F**E=11.96	F
2	**FM**=43.53; **FEM**=24.16	F M
3	**SU**=100	S U
4	**SUM**=42.41; **SFU**=37.86	S U M F
5	**AU**=7.05; **NEAIU**=6.90; **NFEAIU**=6.75; **NAIU**=6.21; **NAU**=5.85; **NEAU**=5.26; **NSFEAIU**=4.98; **NSEAIU**=4.71; **U**=4.44	U A N I E
6	**U**=37.95 A=21.62	U
7	**U**=43.34; **A**=27.46	U A
8	**U**=69.99	S U
9	**U**=44.29; **A**=26.82	U A
10	**SFU**=15.83; **SUM**=15.52; **SAUM**=11.01; **SFAU**=10.05	S U F M

Table S6d. Areas definition for each node in Columbea (1 - 0.1 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**F**=57.63	F
2	**FM**=67.79	F M
3	**SU**=100	S U
4	**SUZ**=52.79	S U Z
5	**NEAIU**=32.90; **NEAU**=13.42; **NFEAIU**=12.74	N E A I U
6	**U**=100.00	U
7	**U**=71.21	U
8	**U**=87.86	U
9	**U**=70.51	U
10	**SUM**=26.77; **SFU** = 24.58	S U M

Appendix 3.8.7.

Table S7a. Areas definition for each node in Caprimulgimorphae (1 - 0.5 - 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=30.13; **S**E=21.65	S
2	**SE**=62.39	S E
3	**E**=100.00	E
4	**E**=49.16; **EA**=44.03	E A
5	**E**=100.00	E
6	**EU**=68.64	E U
7	**E**=29.83; **E**U=24.02	E
8	**E**=31.15; **EU**=26.55	E U
9	**E**=100.00	E
10	**E**=88.01	E
11	**E**=100.00	E
12	**E**=100.00	E
13	**E**=100.00	E
14	**E**=100.00	E
15	**E**=78.68	E
16	**SE**=47.23: **E**=29.65	E S
17	**SE**=50.04	S E

Table S7b. Areas definition for each node in Caprimulgimorphae (1 - 0.25 - 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**SE**=25.66; **S**=24.70	S E
2	**SE**=58.77	S E
3	**E**=86.82	E
4	**E**=50.72	E
5	**E**=100.00	E
6	**EU**=69.38	E U
7	**E**=34.45; **E**U=23.47	E
8	**E**=36.24; **EU**=27.99	E U
9	**E**=100.00	E
10	**E**=87.21	E
11	**E**=100.00	E
12	**E**=100.00	E
13	**E**=100.00	E
14	**E**=100.00	E
15	**E**=82.32	E
16	**SE**=44.67; **E**=38.82	E S
17	**SE**=46.22; **E**=29.12	E S

Table S7c. Areas definition for each node in Caprimulgimorphae (1 - 0.5 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand

Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=61.10	S
2	**SE**=30.46; N**E**=18.53; **E**=14.38	E S
3	**E**=72.05	E
4	**E**=58.22	E
5	**E**=100.00	E
6	**EAU**=31.93; **EA**=24.91	E A U
7	**A**=41.83; **E**=38.80	A E
8	**E**=41.22; **EA**=30.99	E A
9	**E**=100.00	E
10	**E**=77.22	E
11	**E**=100.00	E
12	**E**=100.00	E
13	**E**=100.00	E
14	**E**=100.00	E
15	**E**=45.94; **SE**=36.98	E S
16	**SE**=50.35	S E
17	**SE**=40.70; N**SE**=19.34	S E

Table S7d. Areas definition for each node in Caprimulgimorphae (1 - 0.1 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand

Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=61.61	S
2	S**E**=21.03; N**EA**=11.09; **E**=9.25; NA=8.35	E
3	**E**=24.42; **A**=23.54; **EA**=19.77	E A
4	**EA**=25.06; **E**=23.39; **EAU**=11.93	E A
5	**E**=40.76; **A**=39.29	E A
6	**EAU**=34.11; **EU**=22.29	E U A
7	**A**=67.51	A
8	**A**=60.49	A
9	**A**=50.90	A
10	**A**=54.83	A
11	**A**=52.10	A
12	**A**=57.03	A
13	**A**=55.61	A
14	**A**= 55.01	A
15	**A**=35.53; **E**=25.13	A E
16	**SE**=17.99; **SEA**=10.39; N=9.80; **A=9.55; SA**=7.70	S E A
17	**SEA**=11.65; **SE**=11.03; N**SEA**=8.99; N**SE**=6.86; **SFEA**=4.53; **SEAI**=4.04; N**SFEA**=3.99	S E A

Appendix 3.8.8.

Table S8a. Areas definition for each node in Otidimorphae (1 - 0.5 - 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand

Node	Probability of combinations % (until 50%)	Defined areas
1	**SFIM**=100.00	S F I M
2	**F**=100.00	F
3	**FEAIU**=20.90; **F**=19.84; **FEAI**=11.44	F E A I
4	**F**=87.51	F
5	**SFIM**=100.00	S F I M

Table S8b. Areas definition for each node in Otidimorphae (1 - 0.25 - 0.1 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand

Node	Probability of combinations % (until 50%)	Defined areas
1	**SFIM**=100.00	S F I M
2	**F**=100.00	F
3	**F**=24.94; **FE**AIU=17.21; **FE**=10.46	F E
4	**F**=100.00	F
5	**SFIM**=100.00	S F I M

Table S8c. Areas definition for each node in Otidimorphae (1 - 0.5 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand

Node	Probability of combinations % (until 50%)	Defined areas
1	**SFIM**=100.00	S F I M
2	**F**=100.00	F
3	**FEAIU**=25.99; **F**=16.60, **FEAI**=12.41	F E A I U
4	**F**=85.37	F
5	**SFIM**=100.00	S F I M

Table S8d. Areas definition for each node in Otidimorpha (1 - 0.5 - 0 Model).
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand

Node	Probability of combinations % (until 50%)	Defined areas
1	**SFIM**=100.00	S F I M
2	**F**=100.00	F
3	**F**=31.02; **F**E=22.12	F
4	**F**=100.00	F
5	**SFIM**=100.00	S F I M

Appendix 3.8.9.

Table S9a. Areas definition for each node in Cursoriomorphae - Gruiformes (1 - 0.5 - 0.1 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand

Node	Probability of combinations % (until 50%)	Defined areas
1	**NS**=66.42	N S
2	**FE**=100.00	F E
3	**NE**=42.19; **E**=27.15	N E
4	**N**=49.51; **E**=29.11	N E
5	**N**=42.97; SE=18.21	N
6	**N**=29.64; **S**=25.67	N S
7	**FE**=100.00	F E
8	**NSFI**=50.50	N S F I
9	**FE**=55.57	F E
10	**FEZ**=43.05; N**FEZ**=14.54	F E Z
11	**FEZ**=25.74; NFEZ=24.72	F E Z
12	**NFEZ**=27.86; **NSFEZ**=21.22; **SFEZ**=18.18	N E S F Z

Table S9b. Areas definition for each node in Cursoriomorphae - Gruiformes (1 - 0.25 - 0.1 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand

Node	Probability of combinations % (until 50%)	Defined areas
1	**NS**=62.51	N S
2	**FE**=100.00	F E
3	**NE**=29.66; **E**=25.84	N E
4	**N**=33.39; **E**=25.51	N E
5	**N**=32.07; SE=22.23	N
6	**S**=27.16; **N**=21.17; **NS**=19.06	N S
7	**FE**=100.00	F E
8	**NSFI**=44.38; **NSF**=22.91	N S F I
9	**FE**=59.38	F E
10	**FEZ**=50.19	F E Z
11	**FEZ**=27.28; **NFEZ**=25.41	N F E Z
12	**NFEZ**=26.23; **NSFEZ**=22.25; **SFEZ**=20.77	N F E Z S

Table S9c. Areas definition for each node in Cursoriomorphae - Gruiformes (1 - 0.5 - 0 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand

Node	Probability of combinations % (until 50%)	Defined areas
1	**NS**=70.89	N S
2	**FE**=100.00	F E
3	**NE**=69.03	N E
4	**N**=58.75	N
5	**N**=53.94	N
6	**N**=37.86**; NS**=36.45	N S
7	**FE**=100.00	F E
8	**NSFI**=46.84; **NSFAI**=30.94	N S F A I
9	**FE**=50.22	F E
10	**FEZ**=45.43; N**FEZ**=18.30	F E Z
11	**NFEZ**=22.47; **FEZ**=21.11; **FEAZ**=7.73	F E Z
12	**NFEZ**=26.23; **NSFEZ**=13.30; **NSFEIZ**=10.50	N F E Z

Table S9d. Areas definition for each node in Cursoriomorphae - Gruiformes (1 - 0.1 - 0 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand

Node	Probability of combinations % (until 50%)	Defined areas
1	**NS**=82.95	N S
2	**NA**=41.81; **N**=23.61	N A
3	**N**=85.75	N
4	**N**=100.00	N
5	**NS**=54.33	N S
6	**NS**=49.82; **N**=29.14	N S
7	**N**=65.06	N
8	**NSFA**=51.35	N S A F
9	**N**=16.05; **NSFA**=8.71; **NSF**=7.67; **NZ**=6.12; **NAZ**=4.51; **NFAZ**=3.92; **NSA**=3.71	N
10	**NZ**=18.31; **NSFAZ**=8.95; **NSFZ**=8.40; **NAZ**=6.41; **NFAZ**=5.77; **NFZ**=5.47	N F Z
11	**NZ**=11.61; **NSFAZ**=6.41; **NAZ**=5.42; **NEZ**=4.97; **NSFEAZ**=4.68; **NSFZ**=4.42; **NSFEZ**=4.09; **NFAZ**=4.05; **NFEAZ**=4.00; **NEAZ**=3.93	N F A Z
12	**NSFAZ**=6.89; **NZ**=6.67; **NSFEAZ**=5.45; **NSZ**=5.18; **NSFZ**=4.92; **NSFEZ**=4.81; **NSAZ**=4.66; **NSEZ**=3.86; **NSEAZ**=3.64; **NAZ**=3.05; **NEZ**=2.63	N S Z

Appendix 3.8.10.

Table S10a. Areas definition for each node in Cursoriomorphae - Charadriiformes (1 - 0.5 - 0.1 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**U**=39.98; **SU**=29.92	S U
2	**ST**=85.75	S T
3	**SU**=37.68; **SFU**=22.51	S U
4	**A**=43.16; **E**=29.14	A E
5	**NS**=4.10; **NAU**=3.94; **NSF**=3.89; **NF**=3.52; **NSFU**=3.46; **NA**=3.13; **NFAU**=3.07; **NSU**=3.04; **NSFUZ**=2.96; **N**=2.91; **NU**=2.89; **NSFAU**=2.84; **NSAU**=2.80; **NFU**=2.73; **NSFZ**=2.56; **NFA**=2.40; **NFUZ**=2.36	N S F U
6	**A**=55.12	A
7	**A**=63.17	A
8	**A**=61.46	A
9	**FA**=32.44; **A**=26.19	F A
10	**A**=64.49	A
11	**A**=64.70	A
12	**N**=100.00	N
13	**SU**=56.68	S U
14	**SFEAU**=16.51; **FEA**=13.64; **FEAU**=12.21; **SFEA**=12.12	S F E A U
15	**F**=100.00	F
16	**F**=69.92	F
17	**F**=16.17; **SF**=8.81; **SFU**=8.06; **S**=6.29; **FU**=6.16; **U**=5.80	F
18	**NSFU**=5.94; **NSF**=5.29; **NSFEAU**=5.25; **NSFAU**=4.88; **NFEAU**=4.46; **NSFE**=4.43 **NFAU**=4.15 **NSFEA**=4.00 **NSFA**=3.73 **NF**=3.32 **NSFEU**=2.99 **NFU**=2.90	N S F A U
19	**E**=74.74	E
20	**E**=71.20	E
21	**E**=100.00	E
22	**E**=62.45	E
23	**E**=72.45	E
24	**E**=100.00	E
25	**E**=100.00	E
26	**E**=100.00	E
27	**E**=100.00	E
28	**NSFEAU**=6.06; **NSFE**=5.67; **E**=5.56; **NSFEU**=5.55; **NFE**=5.07; **NSFEA**=4.88; **NFEAU**=4.85; **NFEA**=4.56; **FE**=4.48; **NEA**=3.93	N F E A
29	**NSFEAU**=4.16 **SFEAU**=3.58 **NSFEA**=3.22 **NFEAU**=3.14 **SFEA**=2.62 **NSFEU**=2.51 **SEAU**=2.49 **FEAU**=2.22 **NSFAU**=2.15 **SFEU**=2.09 **NSEAU**=2.06 **SFAU**=1.99 **NFEU**=1.81 **NFEA**=1.76 **NSFE**=1.62 **NSFA**=1.57 **NEAU**=1.54 **NFAU**=1.53 **NSEA**=1.49 **SEA**=1.47 **NSFEAUM**=1.35 **NSFEAUZ**=1.31 **NSFEATU**=1.29 **SFEATU**=1.25	N S F E A U

Table S10b. Areas definition for each node in Cursoriomorphae - Charadriiformes (1 - 0.25 - 0.1 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**U**=43.86; **SU**=27.17	S U
2	**ST**=85.12	S T
3	**SU**=39.58; **SFU**=23.89	S F U
4	**E**=39.21; **A**=32.10	E A
5	**NF**=5.56; **NFU**=4.64; **NAU**=4.41; **NSF**=4.40; **NS**=4.02; **NSFU**=3.98 **NSFUZ**=3.60; **NFUZ**=3.51; **NFZ**=3.41; **NSU**=3.39; **NSFZ**=3.06; **N**=2.60 **NFAU**=2.57; **NSUZ**=2.56	N S F U
6	**A**=38.42; **E**=30.71	A E
7	**A**=46.09; **E**=32.06	A E
8	**A**=43.43; F=21.65	A
9	**FA**=24.57; **F**=22.35; **A**=14.84	F A
10	**A**=46.32; **E**=27.43	A E
11	**A**=40.49; **F**=31.16	A F
12	**N**=100.00	N
13	**SU**=55.27	S U
14	**SFEAU**=17.91; **FEAU**=13.09; **FEA**=11.04; **SFEA**=10.92	S F E A U
15	**F**=100.00	F
16	**F**=55.97	F
17	**F**=18.09; U=13.81; S=9.22; S**F**=6.97; **F**U=6.82	F
18	**NSFEAU**=5.50; **NSFAU**=5.05; **NFEAU**=5.04; **NFAU**=4.86; **NSFU**=4.55; **NSF**=3.65; **NAU**=3.61; **NFU**=3.16; **NSFEA**=3.09; **NSFE**=2.99; **NSFA**=2.88; **NSFEU**=2.69; **NEAU**=2.68; **NF**=2.63	N S F E A U
19	**E**=78.40	E
20	**E**=83.56	E
21	**E**=100.00	E
22	**E**=56.21	E
23	**E**=68.79	E
24	**E**=87.90	E
25	**E**=100.00	E
26	**E**=100.00	E
27	**E**=100.00	E
28	**E**=6.39; N**SFEA**U=6.37; **NFEA**U=5.43; N**SFE**U=4.72; N**SFEA**=4.31; **NFEA**=4.26; **EA**=4.18; N**SFE**=4.16; **NEA**=4.05; **FE**=4.04	E N F A
29	**NSFEAU**=3.83; **SFEAU**=3.32; **NSFEU**=3.26; **NFEAU**=2.93; **NSFEA**=2.91; **SFEA**=2.51; **SFEU**=2.50; **NFEU**=2.42; **FEAU**=2.33; **NSFE**=2.13; **SEAU**=1.93 **NSFAU**=1.71; **SFAU**=1.65; **NSEAU**=1.64; **NFEA**=1.53; **FEU**=1.48; **SFE**=1.48; **NFAU**=1.27 **NSFEAU**M=1.27; **NSFEAUZ**=1.22; **NSFA**=1.22; **NSFEAIU**=1.21; **SEA**=1.18; **NSFEATU**=1.17; **NEAU**=1.14; **NSEU**=1.13	N S F E A U

Table S10c. Areas definition for each node in Cursoriomorphae - Charadriiformes (1 - 0.5 - 0 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**SFU**=24.30; **SFAU**=9.48; N**SFAU**=7.47; **SFUZ**=6.61; N**SF**EA**U**=6.31	S F U
2	**ST**=85.85	S T
3	**SF**T**U**=11.82; **SFU**=11.29; N**SFAU**=6.52; N**SAU**=5.67; N**SF**EA**U**=5.50; N**SFU**=4.88; **SFAU**=4.53	S U F
4	**E**=46.84; **A**=44.11	E A
5	**NSFEAU**=7.10; **NSFAU**=6.94; **NSEAU**=5.68; **NSAU**=5.32; **NFEAU**=4.57; **NEAU**=3.91; **NSFU**=3.77; **NSEA**=3.60; **NSA**=3.59; **NSFEA**=3.56; **NFAU**=3.47	N S F E A U
6	**A**=48.61; **E**=42.95	A E
7	**A**=50.35	A
8	**A**=48.83	A
9	**E**=19.48	E
10	**A**=51.05	A
11	**A**=63.09	A
12	**N**=76.98	N
13	S**U**=14.52; **NA**=14.28; **NAU**=14.05; **NU**=9.71	U A N
14	**NFEA**=13.14; **NEA**=10.05; N**SFEA**=8.79; **NFEA**U=7.65; **FEA**=6.76; N**SEA**=6.73	N F E A
15	**A**=34.66; **F**=29.80	A F
16	**A**=45.65; F=17.39	A
17	**A**=32.32; **N**=17.14; **NA**=11.44	A N
18	**NA**=14.38; **N**=12.27; N**EA**=10.26; N**E**=8.57; **A**=7.94	N A
19	**E**=75.91	E
20	**E**=82.17	E
21	**E**=86.13	E
22	**E**=81.46	E
23	**E**=100.00	E
24	**E**=100.00	E
25	**E**=100.00	E
26	**E**=100.00	E
27	**E**=100.00	E
28	**NE**A=20.32; **E**=18.00; **NE**=17.11	N E
29	**SFEAU**=2.40; **NSFEAU**=1.92; **SEAU**=1.82; **SFEATU**=1.72; **NSEAU**=1.67; **NSFEU**=1.40; **SFEU**=1.37; **NSFEATU**=1.34; **NSFAU**=1.14; **SFEAU**Z=1.12; **SFEAU**M=1.07; **FEATU**=1.05; **SEATU**=1.05; **NSEATU**=1.01; **NSFETU**=0.98; **SEA**=0.98; **SEAU**M=0.98; **NSFEA**=0.97; NSEA=0.97; **NFEATU**=0.96; **SFETU**=0.96; **SFEA**=0.94; **NSFEAUZ**=0.94; **NSFEAU**M=0.90; **NSEU**=0.90; **SFEAIU**=0.88; **SFAU**=0.88; **SEU**=0.88; **SFEATU**Z=0.88; **NEAU**=0.86; **SFEATU**M=0.84; **NSEAU**M=0.83; **NFEAU**=0.83; **NSFEAIU**=0.80; **NEATU**=0.79; **NSFATU**=0.79; **NEA**=0.77; **SEAU**Z=0.75; **NSEAUZ**=0.74; **SFEA**Z=0.74; **NSFEATUZ**=0.74; **EATU**=0.73; **NSFEATU**M=0.70; **NFETU**=0.69; **SFEAITU**=0.69; NSEAIU=0.67; **NSFEA**Z=0.67; **SEATU**M=0.67; **SEAIU**=0.66; **NSFEUZ**=0.66	A E U S F N

Table S10c. Areas definition for each node in Cursoriomorphae - Charadriiformes (1 - 0.1 - 0 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**SFU**=59.64	S F U
2	**ST**=82.29	S T
3	**SFU**=38.87; **SFTU**=21.40	S F U
4	**E**=48.58; **A**=36.46	E A
5	**NEAU**=10.03; **NSEAU**=8.53; **NEAIU**=5.46; **NFEAU**=5.01; **NSFEAU**=4.76; **NSEAIU**=4.65; **NSFU**=3.80; **NSEU**=3.75; **NEU**=3.59; **NEAUZ**=3.52	N S E A U
6	**E**=45.99; **A**=38.68	E A
7	**E**=47.66; **A**=39.10	E A
8	**E**=46.07**;** **A**=31.16	E A
9	**E**=30.89; **EA**=17.42; F**E**=10.45	E
10	**E**=54.93	E
11	**A**=47.97; **E**=33.94	A E
12	**N**=67.60	N
13	**NU**=27.16; S**U**=24.07	U N
14	**EA**=11.34; **FEA**=10.98; N**FEA**=8.92; N**EA**=7.89; **E**=7.17; N**FEAU**=6.25	F E A
15	**A**=31.47; **F**=28.53	A F
16	**A**=44.53; E=23.79	A
17	**A**=27.54; N**A**U=15.31; NE**A**U=7.95	A
18	**NAU**=11.85; NE**AU**=11.65; **NA**=10.96; **NEA**=8.36; **A**=6.81; **NSAU**=6.65	N A U
19	**E**=76.24	E
20	**E**=80.49	E
21	**E**=69.12	E
22	**E**=68.88	E
23	**E**=86.27	E
24	**E**=100.00	E
25	**E**=100.00	E
26	**E**=100.00	E
27	**E**=100.00	E
28	**NEA**=18.55; **EA**=15.54; **E**=11.21; **NEA**U=11.09	N E A
29	**SFEAU**=4.47; **SFEATU**=3.14; N**SFEAU**=2.96; **SFEU**=2.70; N**SFEU**=2.51; N**SFEATU**=2.07; **SFEAU**M=2.00; **SFEAUZ**=1.99; **SEAU**=1.91; **SFEAIU**=1.87; **SFETU**=1.85; N**SFAU**=1.77; N**SFETU**=1.75; **SFAU**=1.63; N**SEAU**=1.60; **SFEATUZ**=1.53; **SFEATU**M=1.52; N**SFEAIU**=1.50; N**SFEA**=1.44; N**SFEAU**M=1.43; **SFEA**=1.40; N**SFEAUZ**=1.40; **SFEAITU**=1.38; N**SFATU**=1.22; **SFEIU**=1.19; **SFEUZ**=1.15; **SFEU**M=1.15	S F E A U

Appendix 3.8.11.

Table S11a. Areas definition for each node in Phaethontimorphae-Aequornithia (1 - 0.5 - 0.1 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=70.43	S
2	**S**=66.98	S
3	**F**=27.02; A=19.23; S=19.20	F
4	**S**=25.50; **S**U=11.32; N**S**=10.07; N**S**U=9.77	S
5	**N**=51.27	N
6	**STZ**=100.00	S T Z
7	**NSTZ**=100.00	N S T Z
8	**S**=81.05	S
9	**S**=81.88	S
10	**S**=86.82	S
11	**S**=43.51; **S**E=21.74	S
12	**NS**=30.41; **NS**E=18.54; **NS**A=17.39	N S
13	**N**=83.75	N
14	**NSTZ**=33.71; **N**=22.42	N S T Z
15	**A**=20.39; N**A**=12.78; F**A**=7.63; NE**A**=6.77; E**A**=5.84	A
16	**N**=36.90; **NA**=25.49	N A
17	**NEA**=15.80; **EA**=13.23; **NE**=10.25; **NFEA**=8.08; **E**=7.35	N E A
18	**SFIU**=25.73; **SFAIU**=16.94; **SIU**=9.45	S F I U
19	**A**=62.05	A
20	**A**=66.82	A
21	**A**=57.78	A
22	**A**=53.97	A
23	**N**=45.24; **A**=40.45	N A
24	**A**=52.95	A
25	**N**=100.00	N
26	**NFEA**=14.05; **NEA**=9.28; **NFE**=8.02; **FEA**=6.53; **EA**=5.54; **NFEAI**=5.47; **NFEAU**=5.19	N F E A
27	**F**=100.00	F
28	**NFEA**=21.12; **NFE**=12.20; **FEA**=11.03; **FE**=8.21	N F E A
29	**N**=54.42	N
30	**NA**=34.06; **N**=27.17	N A
31	**N**=63.30	N
32	**N**=55.33	N
33	**N**=63.18	N
34	**N**=79.80	N
35	**N**=72.26	N
36	**NSATZ**=24.95; **NSTZ**=12.20; **NSAZ**=7.83; **NSU**=7.16	N S A T Z

Table S11b. Areas definition for each node in Phaethontimorphae-Aequornithia (1 - 0.25 - 0.1 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=81.53	S
2	**S**=67.05	S
3	**F**=32.00; **S**=25.07	F S
4	**S**=33.32; **SU**=14.65; **SF**=12.46	S
5	**N**=46.94; **S**=31.34	N S
6	**STZ**=100.00	S T Z
7	**NSTZ**=100.00	N S T Z
8	**S**=75.31	S
9	**S**=76.04	S
10	**S**=80.42	S
11	**S**=47.27; **SE**=16.53	S
12	**NS**=24.54; **NSA**=16.53; **S**=14.67	N S
13	**N**=82.86	N
14	**NSTZ**=39.79; **N**=20.18	N S T Z
15	**A**=15.76; **NA**=12.63; **EA**=6.24; **NEA**=6.17; F=5.78	A
16	**N**=41.71; **NA**=28.04	N A
17	**NEA**=20.59; **EA**=15.76; **E**=9.19; **NE**=9.03	N E A
18	**SFIU**=27.93; **SFAIU**=13.01; **SIU**=11.53	S F I U
19	**A**=53.75	A
20	**A**=58.09	A
21	**A**=54.37	A
22	**A**=49.68; **N**=42.08	A N
23	**N**=49.14; **A**=37.97	N A
24	**A**=45.13; **NA**=15.19	A
25	**N**=100.00	N
26	**NFEA**=13.21; **NEA**=7.08; **NFEAU**=6.96; **NFEAI**=6.24; **NFE**=6.15; **FEA**=5.92; **F**=5.88	N F E A
27	**F**=100.00	F
28	**NFEA**=19.30; **FEA**=9.59; **NFEAU**=9.24; **NFE**=9.01; **NFEAI**=8.52	N F E A
29	**N**=55.26	N
30	**NA**=36.63; **N**=27.68	N A
31	**N**=64.35	N
32	**N**=57.90	N
33	**N**=64.61	N
34	**N**=65.10	N
35	**N**=64.97	N
36	**NSATZ**=19.20; **NSTZ**=14.76; **NSU**=5.93; **NSFU**=5.05; **NSZ**=4.99; **NS**=4.87	N S T Z

Table S11c. Areas definition for each node in Phaethontimorphae-Aequornithia (1 - 0.5 - 0 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**N**=70.59	N
2	**N**=80.61	N
3	**N**=35.72; A=19.27	N
4	**N**=23.23; **N**A=14.07; **N**EA=10.79; NS=8.88	N
5	**S**=57.21	S
6	**STZ**=100.00	S T Z
7	**STZ**=41.42; **NSTZ**=41.42	N S T Z
8	**S**=53.61	S
9	**N**=45.05; **S**=35.58	N S
10	**N**=61.44	N
11	**N**=59.42	N
12	**N**=24.65; **NS**=15.35; **NS**A=10.52	N S
13	**N**=65.68	N
14	**NSTZ**=58.92	N S T Z
15	**NEA**=8.64; N**FEA**=7.76; **NFEAI** 5.57; **NEAI** 5.41; **NA**=5.23; **N**=4.64; **NE**=3.81; N**SEA**=3.43; F**EA**=3.42; **E**=3.34	N E A
16	**N**=35.04; **NA**=14.39; **NEA**=13.03	N A
17	**NEA**=12.69; **E**=9.26; N**FEA**=8.87; **NE**=7.22; **EA**=6.02; **NEAU**=6.01; **NFEAU**=5.46	N E A
18	**NSF**E**AIU**=15.11; **NSFAIU**=14.18; **SFAIU**=7.89; **NSAU**=6.10; **SF**E**AIU**=5.55; **SAU**=5.14	N S F A I U
19	**N**=53.52	N
20	**N**=55.09	N
21	**N**=56.39	N
22	**N**=58.52	N
23	**N**=61.38	N
24	**N**=18.07; **E**=15.24; **NE**A=11.65; **N**A=10.89	N E
25	**N**=61.75	N
26	**E**=22.17; N**EA**=10.51; NF**EA**=9.58; **EA**=8.15	E A
27	**F**=100.00	F
28	**FE**=20.33; N**FEA**=17.57; **FEA**=12.35	F E A
29	**N**=46.51; E=24.18	N
30	**N**=36.51; E=15.56	N
31	**N**=62.57	N
32	**N**=62.87	N
33	**N**=62.15	N
34	**NSTZ**=37.29; **NSZ**=23.09	N S T Z
35	**NSTZ**=40.87; **NSZ**=19.74	N S T Z
36	**NSTZ**=19.31; **NS**E**TZ**=13.53; **NS**A**TZ**=13.45; **NSZ**=10.09	N S T Z

Table S11d. Areas definition for each node in Phaethontimorphae-Aequornithia (1 - 0.1 - 0 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**N**=45.07; **S**=41.32	N S
2	**N**=44.40; **N**S=12.78	N
3	**N**=16.17; **N**A=11.75; A=9.56; EA=8.41; E=8.38	N
4	**NEAI**=15.41; **NEA**=10.75; **NAI**=8.74; **N**=8.12; **NSEAI**=7.87	N E A I
5	**S**=80.01	S
6	**STZ**=100.00	S T Z
7	**STZ**=42.28; N**STZ**=23.67	S T Z
8	**S**=61.28	S
9	**N**=28.68; **S**=20.91; **S**U=17.34	N S
10	**N**=18.07; **NSAU**=11.04; **SAU**=10.58; **NSU**=7.92; **NA**=6.50	N S A U
11	**N**=14.53; **NSAU**=10.02; **NSEAU**=7.68; **NSEAIU**=5.79; **A**=5.53; **NSA**=5.00; **NSAIU**=4.89	N S A U
12	**NSEAU**=10.20; **NSAU**=9.10; **NSEAIU**=8.90; **NSA**=6.65; **NSAIU**=5.97; **NSEA**=5.80; **NEAI**=5.44	N S E A U
13	**S**=46.45; **N**=33.06	S N
14	**NSTZ**=30.00; **STZ**=25.06	N S T Z
15	**NEAI**=21.04; **NEAI**U=12.27; **NFEAI**=9.63; **NEA**=9.06	N E A I
16	**NEAI**=25.18; **NEA**=16.02; **NAI**=11.72	N E A I
17	**NEAI**=17.30; **NEAI**U=13.72; **NEA**=9.18; **NFEAI**=7.88; **NFEAI**U=7.11	N E A I
18	**NFEAIU**=16.56; **NSFEAIU**=15.20; **NEAIU**=7.14; **SFEAIU**=6.90; **NSEAIU**=6.52	N S F E A I U
19	**A**=29.68; **N**=27.73	A N
20	**A**=31.92; **N**=29.23	A N
21	**A**=31.95; **N**=29.50	A N
22	**A**=31.22; **N**=30.64	A N
23	**N**=32.03; **A**=30.28	N A
24	**NEAI**=15.02; **NEA**=12.12; **EAI**=8.59; **EA**=8.32; **NAI**=8.20	N E A I
25	**N**=34.55; A=24.10	N
26	**F**=11.44; **NFEA**IU=10.50; **E**=7.94; **NEA**IU=7.84; **NFEA**U=6.28; **NFEA**I=5.47	N F E A
27	**F**=100.00	F
28	**NFEAIU**=15.88; **F**=11.35; **NFEAI**=10.69; **NFEAU**=10.13; **FE**=9.39	N F E A I U
29	**N**=23.33; A=19.86; E=17.56	N
30	**NEA**=15.01; **NEAI**=12.89; **NA**=11.95; **N**=11.09	N E A
31	**N**=23.07; **N**A=13.95; E=11.81; EA=10.06	N
32	**N**=33.27; **A**=29.48	N A
33	**N**=35.51; **A**=31.12	N A
34	**NSTZ**=20.30; **NSATZ**=12.24; **SETZ**=8.76; **NSZ**=8.14; **NSETZ**=7.50	N S T Z
35	**NSTZ**=19.12; **NSATZ**=11.07; **SETZ**=8.23; **NSETZ**=8.00; **SATZ**=7.45	N S T Z
36	**NSATZ**=10.10; **NSETZ**=7.93; **NSTZ**=7.82; **NSEATZ**=6.33; **NSITZ**=5.18; **NSAITZ**=4.95; **SEATZ**=4.56; **NSEITZ**=3.56	N S T Z

Appendix 3.8.12.

Table S12a. Areas definition for each node in Afroaves (1 - 0.5 - 0.1 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=70.41	S
2	**E**=100.00	N
3	**FE**=69.25	F E
4	**F**=100.00	F
5	**F**=100.00	F
6	**F**=100.00	F
7	**FE**=61.21	F E
8	**FE**=86.88	F E
9	**NFE**=100.00	N F E
10	**FA**=100.00	F A
11	**NFE**=78.73	N F E
12	**NE**=33.90; **E**=28.06	E N
13	**E**=44.67; **NE**=25.70	E N
14	**FE**=69.06	F E
15	**E**=100.00	E
16	**E**=100.00	E
17	**FEM**=100.00	F E M
18	**FE**=100.00	F E
19	**F**=100.00	F
20	**FEA**=32.07; **FEAI**= 28.70	F E A I
21	**E**=83.19	E
22	**E**=67.92	E
23	**S**=100.00	S
24	**FEAI**=100.00	F E A I
25	**E**=48.16; **FE**=34.45	E F
26	**FE**=47.28; **F**=28.85	F E
27	**FEAI**=80.14	F E A I
28	**FEAI**=51.28	F E A I
29	**E**=87.83	E
30	**E**=100.00	E
31	**E**=66.62	E
32	**FM**=100.00	F M
33	**FEM**=84.98	F E M
34	**E**=100.00	E
35	**E**=100.00	E
36	**FEAI**=38.58; **FEA**=28.01	F E A I
37	**E**=100.00	E
38	**N**=69.93	N
39	**NE**=48.28; **E**=34.92	N E
40	**NEA**=28.46; **E**=24.11	E N A
41	**NE**=46.38; **E**=22.49	N E
42	**E**=71.24	E
43	**E**=100.00	E
44	**E**=100.00	E
45	**E**=100.00	E
46	**E**=100.00	E
47	**E**=100.00	E
48	**E**=100.00	E
49	**E**=73.18	E
50	**FE**=29.06; **E**=25.77	E F

Table S12b. Areas definition for each node in Afroaves (1 - 0.25 - 0.1 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=82.91	S
2	**E**=100.00	N
3	**FE**=70.06	F E
4	**F**=100.00	F
5	**F**=100.00	F
6	**F**=100.00	F
7	**FE**=64.61	F E
8	**FE**=87.23	F E
9	**NFE**=100.00	N F E
10	**FA**=100.00	F A
11	**NFE**=75.49	N F E
12	**NE**=33.04; **NFE**=31.65	E N F
13	**E**=31.92; **NE**=23.69	E N
14	**FE**=61.99	F E
15	**E**=100.00	E
16	**E**=100.00	E
17	**FEM**=100.00	F E M
18	**FE**=100.00	F E
19	**F**=100.00	F
20	**FEA**=30.84; **FEAI**=30.05	F E A I
21	**E**=78.68	E
22	**E**=63.25	E
23	**S**=100.00	S
24	**FEAI**=100.00	F E A I
25	**E**=48.24; **FE**=30.46	E F
26	**FE**=38.45; **F**=29.58	F E
27	**FEAI**=81.23	F E A I
28	**FEAI**=51.17	F E A I
29	**E**=87.09	E
30	**E**=100.00	E
31	**E**=64.93	E
32	**FM**=100.00	F M
33	**FEM**=100.00	F E M
34	**E**=100.00	E
35	**E**=100.00	E
36	**FEAI**=42.48; **FEA**=29.08	F E A I
37	**E**=100.00	E
38	**N**=73.34	N
39	**NE**=52.90	N E
40	**NEA**=34.67; **E**=22.64	E N A
41	**NE**=45.66; **NEA**=27.72	N E A
42	**E**=60.05	E
43	**E**=100.00	E
44	**E**=100.00	E
45	**E**=100.00	E
46	**E**=100.00	E
47	**E**=100.00	E
48	**E**=100.00	E
49	**E**=56.84	E
50	**FE**=28.21; **NFE**=25.89	F E N

Table S12c. Areas definition for each node in Afroaves (1 - 0.5 - 0 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**N**=58.60	N
2	**E**=100.00	N
3	**F**=47.42; **FE**=45.24	F E
4	**F**=100.00	F
5	**F**=100.00	F
6	**F**=100.00	F
7	**F**=56.88	F
8	**FE**=100.00	F E
9	**NFE**=100.00	N F E
10	**FA**=100.00	F A
11	**NFE**=68.30	N F E
12	**E**=54.13	E
13	**E**=69.33	E
14	**FE**=60.20	F E
15	**E**=100.00	E
16	**E**=100.00	E
17	**FEM**=100.00	F E M
18	**FE**=100.00	F E
19	**F**=100.00	F
20	**FEA**=34.00; **FEAI**=27.09	F E A I
21	**E**=100.00	E
22	**E**=76.92	E
23	**S**=100.00	S
24	**FEAI**=100.00	F E A I
25	**E**=54.22	E F
26	**FE**=32.78; **F**=31.12	F E
27	**FEAI**=77.63	F E A I
28	**FEAI**=49.40; **FEA**=24.02	F E A I
29	**E**=84.95	E
30	**E**=100.00	E
31	**E**=63.16	E
32	**FM**=100.00	F M
33	**FEM**=76.57	F E M
34	**E**=100.00	E
35	**E**=100.00	E
36	**FEAI**=35.49; **FEA**=30.67	F E A I
37	**E**=100.00	E
38	**N**=58.79	N
39	**E**=44.72; **NE**=29.86	E N
40	**E**=33.61: N**EA**=18.19	E
41	**NE**=33.04; **E**=32.00	N E
42	**E**=71.42	E
43	**E**=100.00	E
44	**E**=100.00	E
45	**E**=100.00	E
46	**E**=100.00	E
47	**E**=100.00	E
48	**E**=100.00	E
49	**E**=100.00	E
50	**E**=34.56; **FE**=28.93	E F

Table S12d. Areas definition for each node in Afroaves (1 - 0.1 - 0 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**N**=73.53	N
2	**E**=100.00	N
3	**F**=67.17	F
4	**F**=100.00	F
5	**F**=100.00	F
6	**F**=100.00	F
7	**F**=66.17	F
8	**FE**=100.00	F E
9	**NFE**=100.00	N F E
10	**FA**=100.00	F A
11	**NFE**=63.88	N F E
12	**E**=35.29; NF**E**=17.08	E
13	**E**=45.49; NF**E**=13.51	E
14	**E**=63.27	F E
15	**E**=100.00	E
16	**E**=100.00	E
17	**FEM**=100.00	F E M
18	**FE**=100.00	F E
19	**F**=100.00	F
20	**FEAI**=28.87; **FEA**=27.88	F E A I
21	**E**=82.32	E
22	**E**=70.04	E
23	**S**=100.00	S
24	**FEAI**=100.00	F E A I
25	**E**=48.79; **F**=42.41	E F
26	**F**=45.62; **E**=39.94	F E
27	**FEAI**=79.83	F E A I
28	**FEAI**=51.72	F E A I
29	**E**=81.43	E
30	**E**=100.00	E
31	**E**=57.49	E
32	**FM**=100.00	F M
33	**FEM**=74.19	F E M
34	**E**=100.00	E
35	**E**=100.00	E
36	**FEAI**=47.11; **FEA**=31.58	F E A I
37	**E**=100.00	E
38	**N**=78.11	N
39	**E**=29.48; N=21.84	E
40	**E**=23.77; N**E**A=22.01	E
41	**NEA**=25.54; **NE**=19.58; **E**=19.48	E N A
42	**E**=49.80; **E**A=20.78	E
43	**E**=100.00	E
44	**E**=100.00	E
45	**E**=100.00	E
46	**E**=100.00	E
47	**E**=100.00	E
48	**E**=100.00	E
49	**E**=85.92	E
50	**FE**=25.97; N**FE**=17.94; **E**=12.63	E F

Appendix 3.8.13.

Table S13a. Areas definition for each node in Australaves (1 - 0.5 - 0.1 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=57.33	S
2	**S**=78.38	S
3	**S**=76.62	S
4	**ST**=100.00	S T
5	**UZ**=100.00	U Z
6	**U**=70.86	U
7	**U**=77.06	U
8	**UZ**=100.00	U Z
9	**U**=68.71	U
10	**STU**=42.01; **SU**=16.91	S T U
11	**STU**=28.93; **SU**=11.13; **ST**Z=10.92	S T U

Table S13b. Areas definition for each node in Australaves (1 - 0.25 - 0.1 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

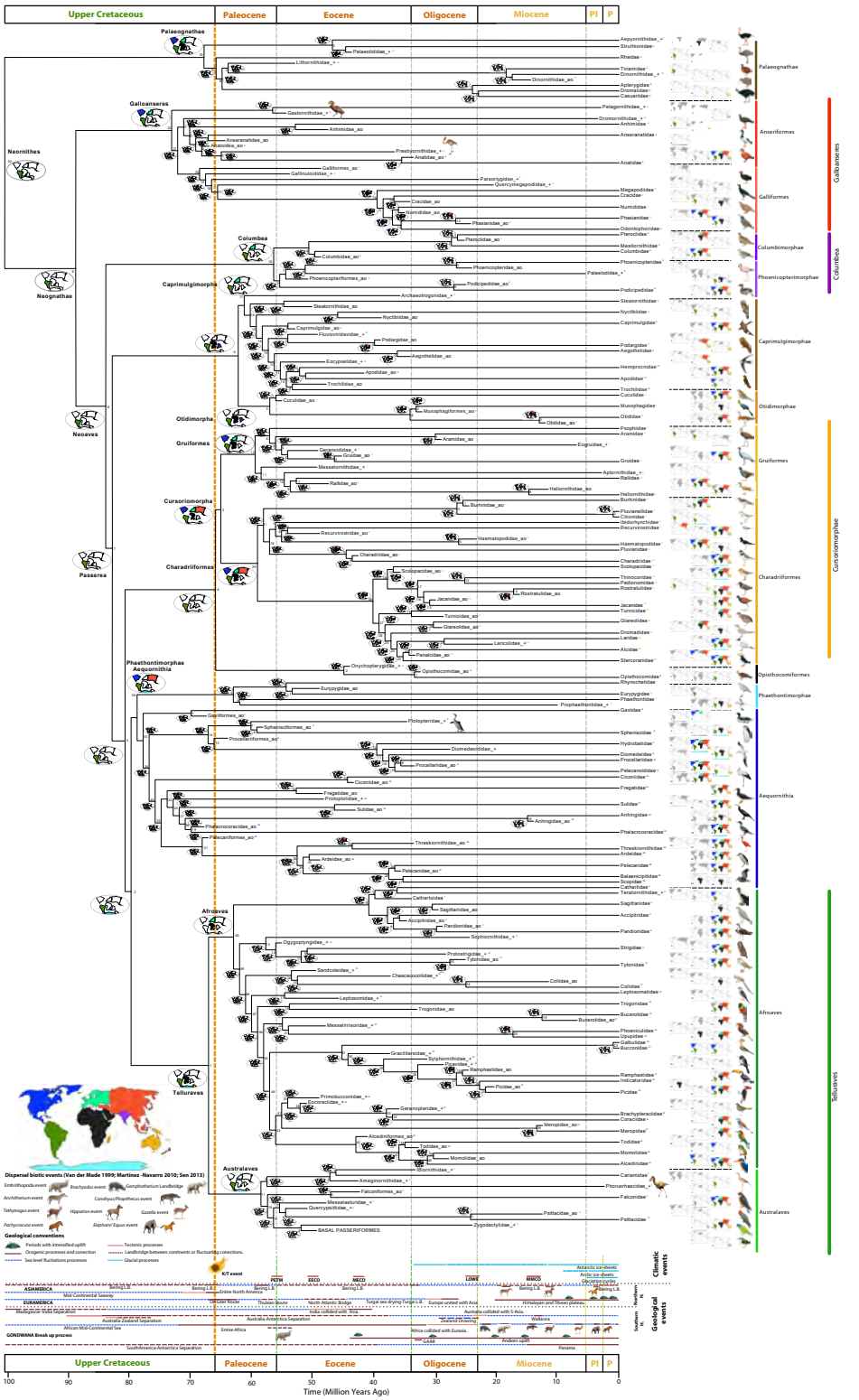
Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=52.84	S
2	**S**=80.02	S
3	**S**=80.56	S
4	**ST**=100.00	S T
5	**UZ**=100.00	U Z
6	**U**=83.05	U
7	**U**=100.00	U
8	**UZ**=100.00	U Z
9	**U**=72.67	U
10	**STU**=33.97; **SU**=18.88	S T U
11	**STU**=30.22; **SU**=16.27; N**STU**=9.42	S T U

Table S13c. Areas definition for each node in Australaves (1 - 0.5 - 0 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=64.29	S
2	**S**=81.61	S
3	**S**=80.22	S
4	**ST**=100.00	S T
5	**UZ**=100.00	U Z
6	**U**=72.08	U
7	**U**=76.85	U
8	**UZ**=100.00	U Z
9	**U**=76.45	U
10	**STU**=56.20	S T U
11	**STU**=43.84; **ST**Z=15.65	S T U

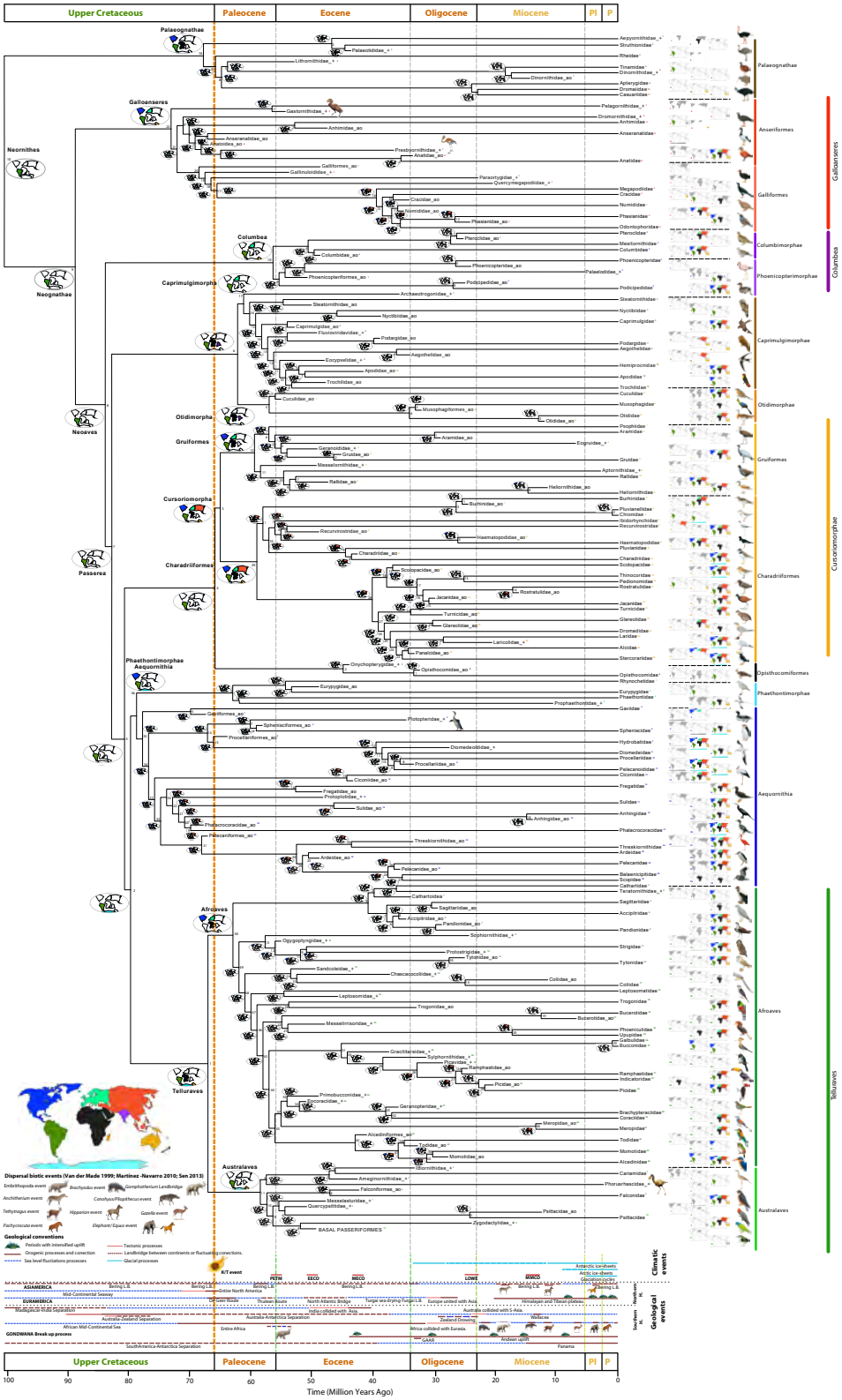
Table S13d. Areas definition for each node in Australaves (1 - 0.1 - 0 Model). **(N)** North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australia; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

Node	Probability of combinations % (until 50%)	Defined areas
1	**S**=77.28	S
2	**S**=100.00	S
3	**S**=100.00	S
4	**ST**=100.00	S T
5	**UZ**=100.00	U Z
6	**U**=100.00	U
7	**U**=100.00	U
8	**UZ**=100.00	U Z
9	**U**=87.32	U
10	**STU**=69.02	S T U
11	**STU**=58.36	S T U



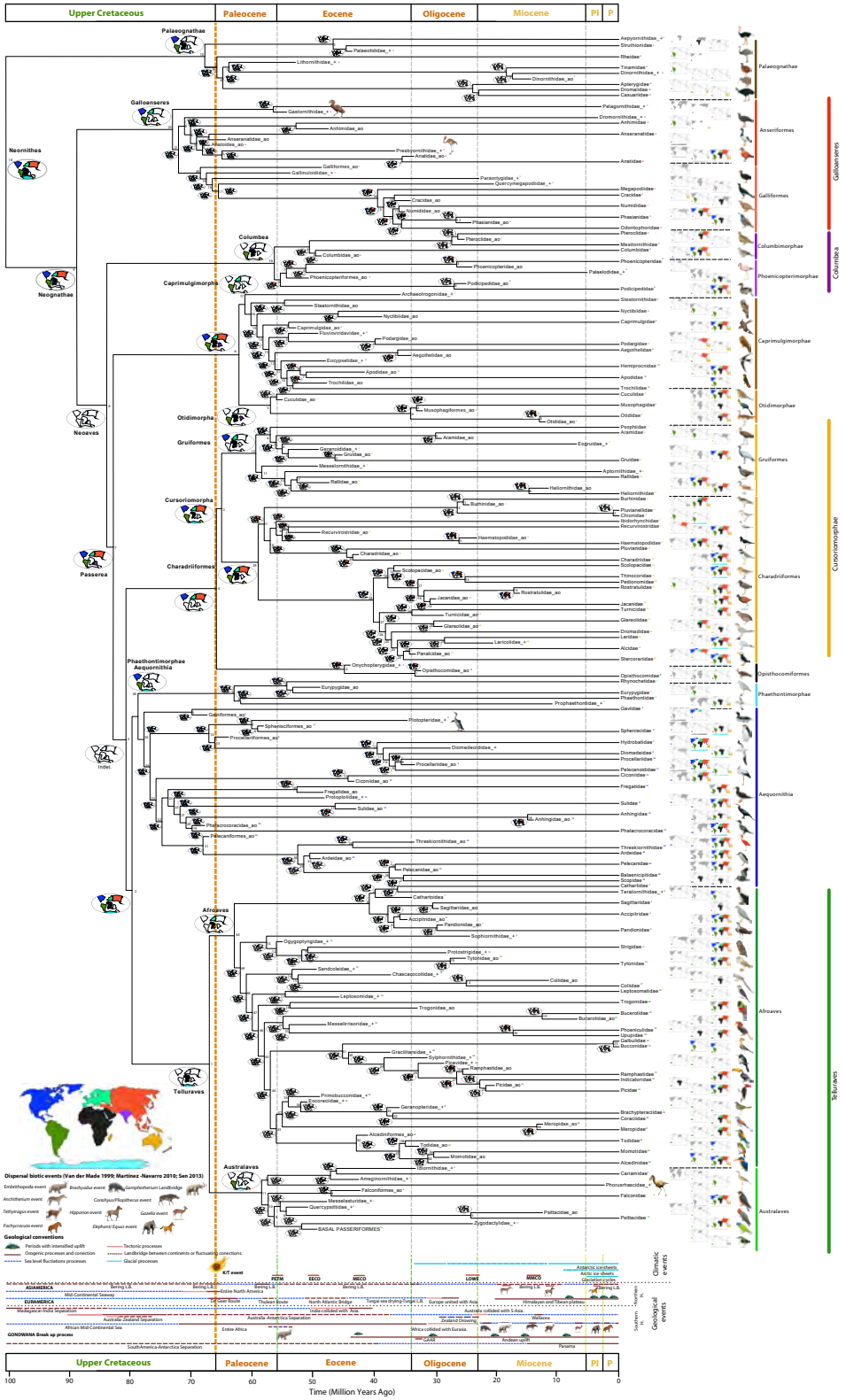
Appendix 3.8.14. Figure S1. Paleobiogeographical reconstruction according with the 1-0.5-0.1 Model using Lagrange (DEC). The inferred ancestral area(s) with the highest relative likelihood (in the nodes) (see Tables S3- S13 for details.) the maps indicate the geographical distribution of families based in the fossil record and their current distribution.

3. Paleobiogeographic history



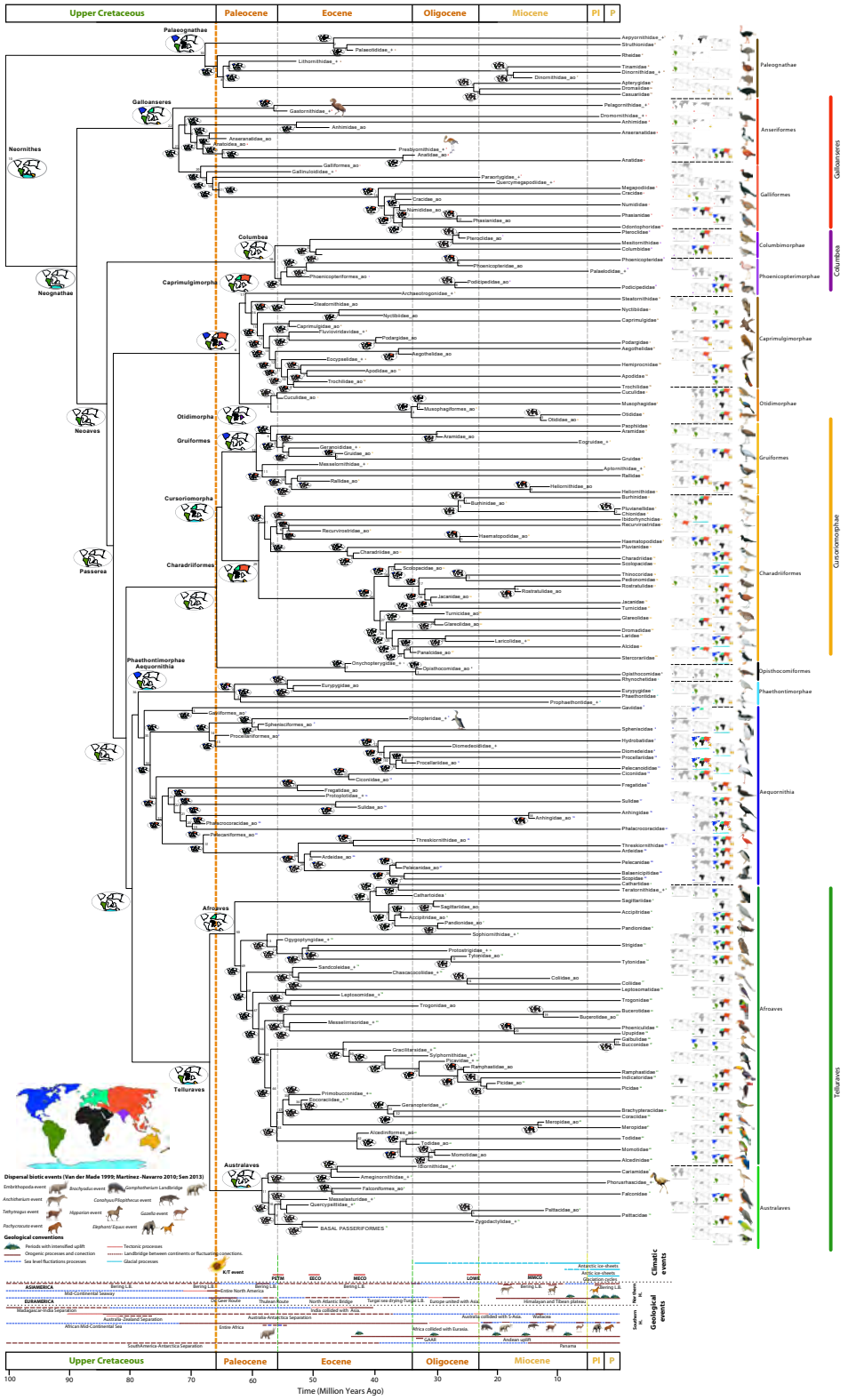
Appendix 3.8.15. Figure S2. Paleobiogeographical reconstruction according with the 1-0.25-0.1 Model using Lagrange (DEC). The inferred ancestral area(s) with the highest relative likelihood (in the nodes) (see Tables S3- S13 for details.) the maps indicate the geographical distribution of families based in the fossil record and their current distribution.

3. Paleobiogeographic history



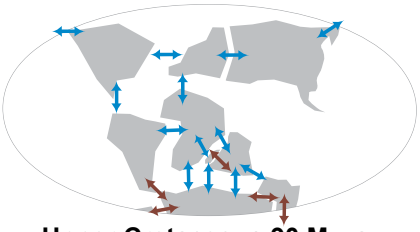
Appendix 3.8.16. Figure S3. Paleobiogeographical reconstruction according with the 1-0.5-0 Model using Lagrange (DEC). The inferred ancestral area(s) with the highest relative likelihood (in the nodes) (see Tables S3- S13 for details.) the maps indicate the geographical distribution of families based in the fossil record and their current distribution.

3. Paleobiogeographic history

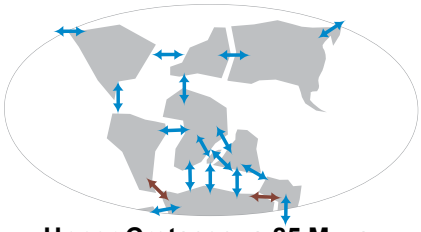


Appendix 3.8.17. Figure S4. Paleobiogeographical reconstruction according with the 1-0.1-0 Model using Lagrange (DEC). The inferred ancestral area(s) with the highest relative likelihood (in the nodes) (see Tables S3- S13 for details.) the maps indicate the geographical distribution of families based in the fossil record and their current distribution.

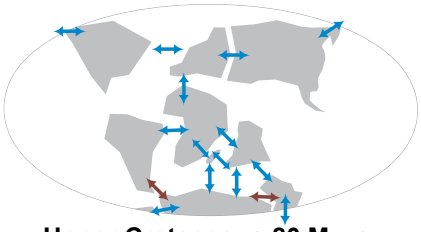
3. Paleobiogeographic history



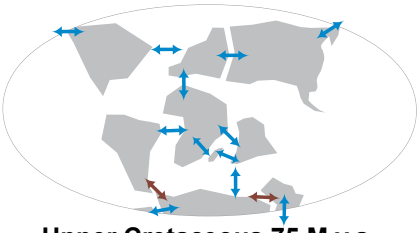
Upper Cretaceous 90 M.y.a
(Turonian-Coniacian)
Gondwana fragmentation [1-13],I+M[14],I/T[6,14]
S+T[1-4,10],S/F[2,5],S/N[2,6-8],U++T+Z[15-18],N/A[2,3]
E/A[2,9], N/A [2,3], F/T[14],F/E[2,10]



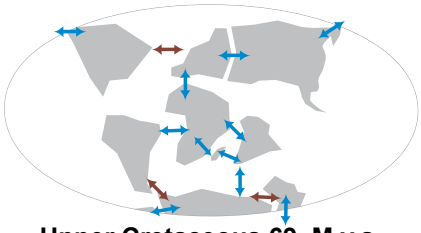
Upper Cretaceous 85 M.y.a
(Santonian)
Gondwana fragmentation [1-13], U+T[1,16],U/Z
[1,19-22], I/M [14,23-29] T/Z [2,18-22]



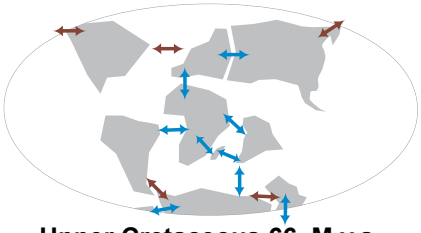
Upper Cretaceous 80 M.y.a
(Campanian)
Gondwana fragmentation [1-13] ,N//S[2,6,12] ,
IM/T[14], I/M[14,26,28] , F//T [2,10,14]



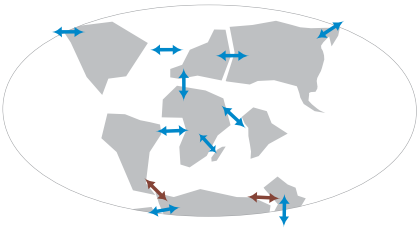
Upper Cretaceous 75 M.y.a
(Maastrichtian)
Gondwana fragmentation [1-13]
I/M[25-29] ,F//T[2,10,14,30]



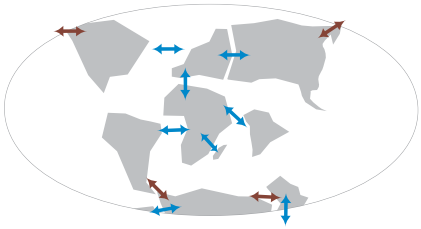
Upper Cretaceous 69 M.y.a
(Maastrichtian)
I/T[26],F/I[25],N+E[31]



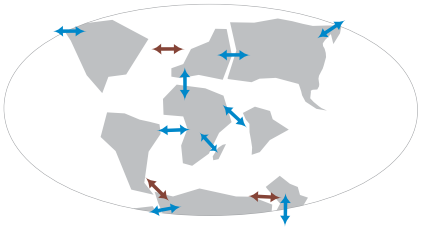
Upper Cretaceous 66 M.y.a
(K/Pg Boundary)
N+A[31,32], E/A[32,33]



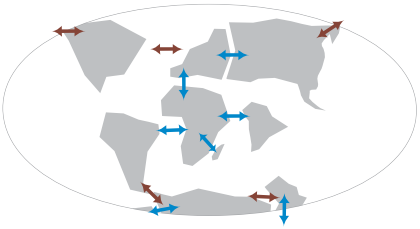
Middle Paleocene 60 M.y.a
(Selandian)
S+T[1], F/I[14,28] , N/E[31,32] ,N/A[31,32] ,E/A[33,34]



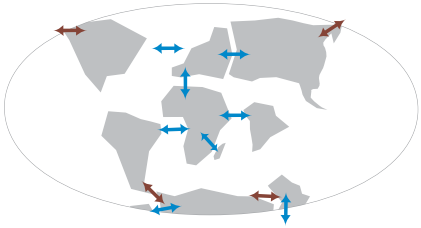
Upper Paleocene 58 M.y.a
(Thanetian)
N+A[31]



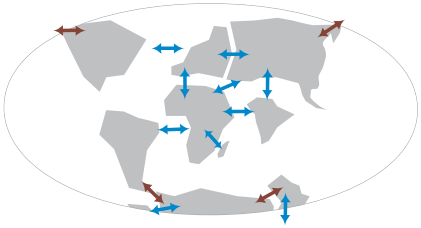
Upper Paleocene 57 M.y.a
(Thanetian)
E/A[33,34] , N/A[31] ,N/E[31]



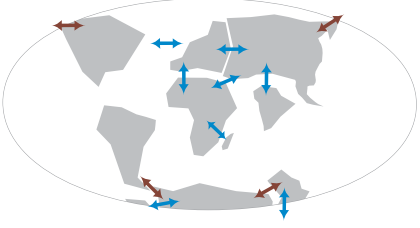
Upper Paleocene 56 M.y.a
(PE/Eo Boundary)
E/A[33,34] ,N+A[35,36]



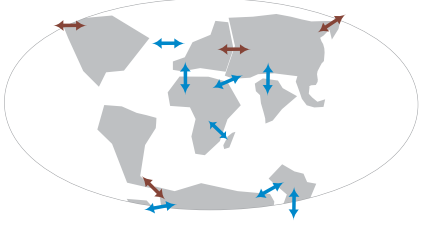
Lower Eocene 55 M.y.a
(Ypresian)
E/A[33,34] , E/N[31]



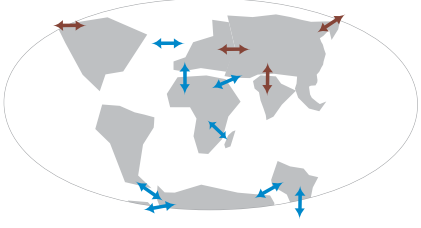
Lower Eocene 50 M.y.a
(Ypresian)
E/A[33,34] ,F/A[10,37], F/I[14], I/A[14,28,29]



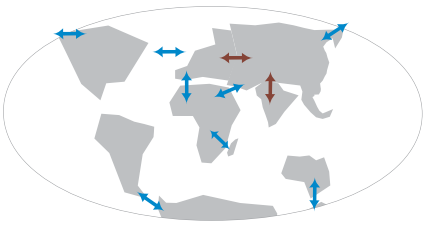
Lower Eocene 48 M.y.a
(Ypresian)
S//F[9],E/A[33,34] ,U+T[15,16, 20, 30,38]



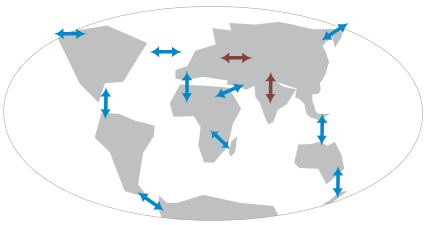
Middle Eocene 40 M.y.a
(Bartonian)
E+A[32-34] ,U/T[15,16, 20, 30]



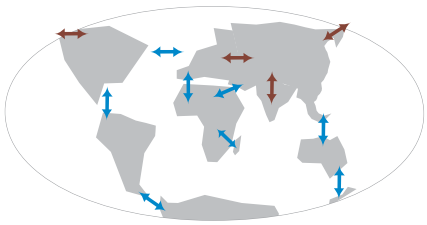
Upper Eocene 34 M.y.a
(Eo/OG Boundary)
E++A[3,32-34], I+A[39] ,S/T[30,38,40]



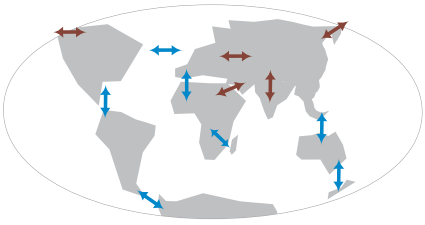
Lower Oligocene 30 M.y.a
(Rupelian)
N/A[36] ,U//T[16,20]



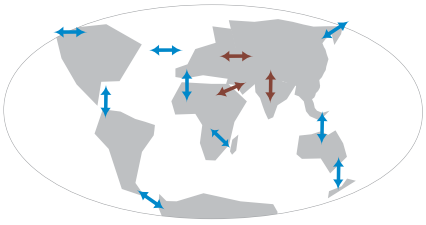
Upper Oligocene 25 M.y.a
(Chattian)
U/A[16,20],S/N[41,42]



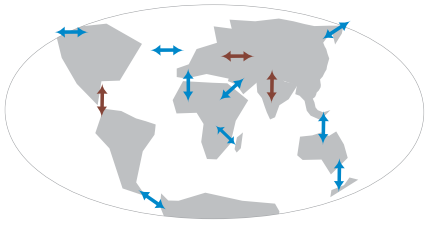
Lower Miocene 20 M.y.a
(Burdigalian)
N+A[43,44]



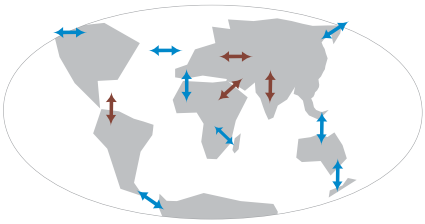
Lower Miocene 18 M.y.a
(Burdigalian)
N+A[43,44] ,A+F [37,43-45]



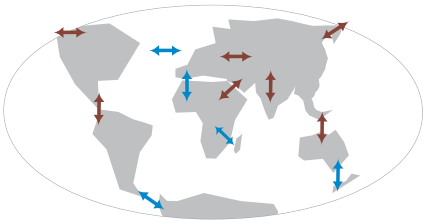
Lower Miocene 17 M.y.a
(Burdigalian)
N/A[43,44]



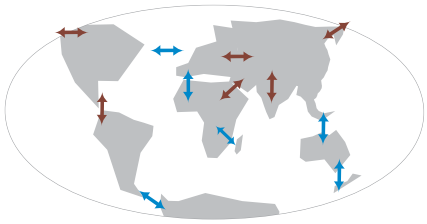
Lower Miocene 15 M.y.a
(Langhian)
F/A[44,45] ,S++N[50-54]



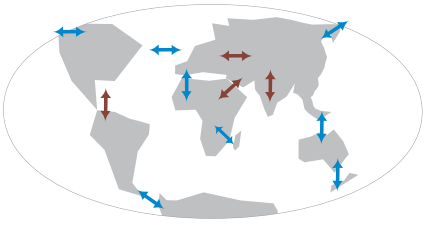
Middle Miocene 13.8 M.y.a
(Serravallian)
F+A[43,45]



Middle Miocene 12 M.y.a
(Serravallian)
U+A[3,16] ,N+A[43,44]



Upper Miocene 10 M.y.a
(Tortonian)
N+A[43,44]



Upper Miocene 7.5 M.y.a
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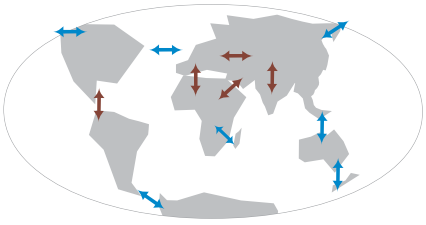
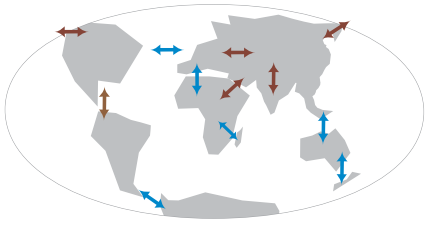
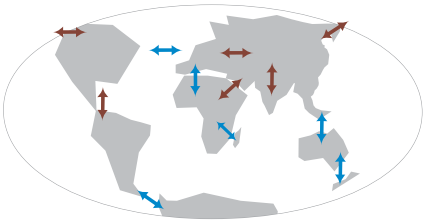
N/A[43,44] ,U/A[3,16]



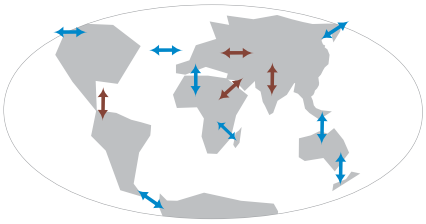
Upper Miocene 5.9 M.y.a
(Messinian)
F+E[43,46]



Lower Pliocene 4.8 M.y.a
(Zanclean)
N+A [47-49], F/E[43,46]



Lower Pliocene 3.5 M.y.a
(Zanclean)
S++N[50-53]



Upper Pliocene 3 M.y.a
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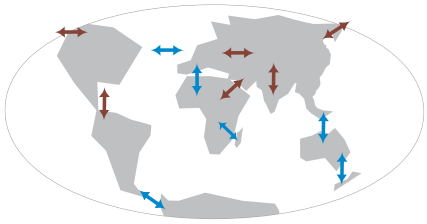
N/A[47-49]



Lower Pleistocene 2 M.y.a
(Gelasian)
N+A [32,47-49]

Appendix 3.8.18. Figure S5. 30 geological periods considered for the paleobiogeographical analysis: (++) complete connection between landmasses; (+) Partial connection between landmasses by bridges or Islands (stepping stones); (/) separations between landmasses by seaway with less than 2000 km of distance each other; (//) complete separation between landmasses with more than 2000 km of distance each other.
(N) North and Central America; **(S)** South America; **(E)** Europe; **(A)** Asia; **(I)** India; **(F)** Africa; **(U)** Australian; **(T)** Antarctica; **(M)** Madagascar; **(Z)** Zealand.

REFERENCES IN PALEOGEOGRAPHIC RECONSTRUCTIONS

***Global processes*: [1-8]; *Gondwana*: [2, 6, 9-14]; *Australia* (U): [15-20]; *New Zealand* (Z): [15, 18, 21, 22]; *Madagascar* (M):[23-26]; *India* (I):[14,17, 23,27-29,39] *Antarctica* (T):[18, 19, 30, 38]; *Africa* (F): [10,37,45,46]; *South America* (S): [40,41,42,50-54]; *North America* (N): [31,32, 35,36,41-44,47-54]; *Europe* (E): [31,33,34,44,46,]; *Asia* (A): [32-37,43-45,47-49].**

1. Sanmartín I, Ronquist F (2004) Southern hemisphere biogeography inferred by event-based models: plant versus animal patterns. *Syst Biol* (53): 216-243
2. Ezcurra MD, Agnolin FL (2012) A new global palaeobiogeographical model for the Late Mesozoic and Early Tertiary. *Syst Biol* 61(4): 553-566
3. Cox CB (2000) Plate tectonics, seaways and climate in the historical biogeography of Mammals. *Mem Inst Oswaldo Cruz, Rio de Janeiro* 95(4): 509-516
4. Givnish TJ, Renner SS (2004) Tropical intercontinental disjunctions: Gondwana breakup, immigration from the Boreotropics, and transoceanic dispersal. *Int J Plant Sci* 165 (Suppl): S1-S6
5. Scotese CR (2001) *Atlas of Earth history-PALEOMAP project*. [cited 2014; Available from: http://www.scotese.com/
6. Hay WW, DeConto RM, Wold CN, Wilson K, Voigt S, Schulz M, et al. Alternative global Cretaceous paleogeography. In: Barrera E, Johnson CC (eds) *Evolution of the Cretaceous Ocean-Climate System*. Special paper. Boulder, Colorado: Geological Society of America; 1999. p. 332
7. Limolino MV, Riddle BR, Whittaker RJ, Brown JH (2010) *Biogeography*. 4 edn. Sinauer Associates, Inc., Sunderlan, MA
8. Renema W (2007) Biogeography, Time, and Place: distributions, barriers, and islands. In: Landman N, Jones D (eds). *Topics in Geobiol* Vol. 29. Dordrecht. The Netherlands.Springer

9. Jacobs LL, Strganac C, Scotese CR (2011) Plate motions, Gondwana Dinosaurs, Noah's Arks, beached Viking funeral ships, ghost ships, and Landspans. *Anais da Academia Brasileira de Ciencias* 83(1): 3-22

10. Gheerbrant E, Rage JC (2006) Paleobiogeography of Africa: how distinct from Gondwana and Laurasia? *Palaeogeogr Palaeoclimatol Palaeoecol* 241: 224-246

11. McGlone MS (2005) Goodbye Gondwana. *J Biogeogr* 32:739-740

12. Scotese CR, Boucot AJ, Mckerrow WS (1999) Gondwanan palaeogeography and palaeoclimatology. *J Afr Earth Sci* 28(1): 99-114

13. Rage J-C (1988) Gondwana, Tethys and terrestrial vertebrates during the Mesozoic and de Cainozoic. In: Audley-Chalres MG, Hallam A (eds). *Gondwana and Tethys*. Geological Society Special Publication. 255-273

14. Chatterjee S, Goswami A, Scotese CR (2013) The longest voyage: Tectonic, magmatic, and paleoclimatic evolution of the Indian plate during its northward flight from Gondwana to Asia. *Gondwana Res* 23: 238-267

15. Li ZX, Powell CM (2001) An outline of the palaeogeographic evolution of the Australasian region since the beginning of the Neoproterozoic. *Earth-Sci Rev* 53: 237-277

16. Hall R (2001) Cenozoic reconstructions of SE Asia and the SW Pacific: changing patterns of land and sea. In: Metcalfe I, et al (eds) *Faunal and Floral Migrations and Evolution in SE Asia-Australasia*. Swets & Zeitlinger Publishers. Lisse. 35-56

17. Lohman DJ, et al (2011) Biogeography of the Indo-Australian Archipelago. *Annu Rev Ecol Evol Syst* 42: 205-226

18. Bijl PK Bendle JAP, Bohaty SM, Pross J, Schouten S, Tauxe L, et al. (2013) Eocene cooling linked to early flow across the Tasmanian Gateway. *Proc Natl Acad Sci USA* 110(24): 9645-9650

19. Sijp WP, England MH, Huber M (2011) Effect of the deepening of the Tasman Gateway on the global ocean. *Paleoceanography* 2011. 26: PA4207

20. Hall R (2009) Southest Asia′s changing palaeogeography. *Blumea* 54:148-161

21. Laird MG, Bradshaw JD (2004) The Break-up of a Long-term Relationship: the Cretaceous Separation of New Zealand from Gondwana. *Gondwana Res* 7(1): 273-286

22. Trewick SA, Gibb G (2010) Vicars, tramps and assembly of the New Zealand avifauna: a review of molecular phylogenetic evidence. *Ibis* 152: 226-253

23. Noonan BP, Chippindale PT (2006) Dispersal and vicariance: The complex evolutionary history of boid snakes. *Mol Phylogenet Evol* 40: 347-358

24. Yoder A, Nowak M (2006) Has Vicariance or Dispersal Been the Predominant Biogeographic Force in Madagascar? Only Time Will Tell. *Annu Rev Ecol Evol Syst* 37: 405-431

25. Warren BH et al. (2010) Why does the biota of the Madagascar region have such a strong Asiatic flavour? *Cladistics* 2010. 26: 526-538

26. Rage J-C (2003) Relationships of the Malagasy fauna during the Late Cretaceous: Northern or Southern routes? *Acta Palaeontol Pol*, 2003. 48(4): 661-662

27. Bocxlaer IV, Roelants K, Biju SD, Nagaraju J, Bossuyt F (2006) Late Cretaceous vicariance in Gondwanan Amphibians. *PLoS ONE* 1 (1):74

28. Chatterjee S, Scotese CR (1999) The breakup of Gondwana and the evolution and biogeography of the Indian plate. *Proc Indian Natl Sci Acad* 65: 397-425

29. Briggs JC (2003) The biogeographic and tectonic history of India. *J Biogeogr* 30: 381-388

30. Boger SD (2011) Antarctica: Before and after Gondwana. *Gondwana Res* 19: 335-371

31. Brikiatis L (2014) The De Geer, Thulean and Beringia routes: key concepts for understanding early Cenozoic biogeography. *J Biogeogr* 1: 1-19

32. O´Regan M Williams CJ, Frey KE, Jakobsson M (2011) A synthesis of the long-term paleoclimatic evolution of the Arctic. *Oceanography* 24(3): 66-80

33. Akhmetiev MA. Beniamovski VN (2006) The Paleocene and Eocene in the Russian Part of West Eurasia. *Stratigraphy and Geological Correlation* 14: 49-72

34. Akhmetiev MA, Zaporozhets NI, Benyamovskiy VN, Aleksandrova GN, Iakovleva AI, Oreshkina TV (2012) The Paleogene history of the Western Siberian seaway: a connection of the Peri-Tethys to the Arctic ocean. *Austrian Journal of Earth Sciences* 105 (1):50-67

35. Milne RI (2006) Northern Hemisphere Plant Disjunctions: A Window on Tertiary Land Bridges and Climate Change? *Annals of Botany (London)* 98: 465-472

36. Tiffney BH (2008) Phylogeography, fossils and northern hemisphere biogeography: the role of physiological uniformitarianism. *Ann Mo Bot Gard* 95 (1):135-143

37. Sen S (2013) Dispersal of African mammals in Eurasia during the Cenozoic: Ways and whys. *Geobios* 46: 159-172

38. Lawver LA, Gahagan LM, Coffin MF (1992) The development of paleoseaways around Antarctica. *Antarctic Research Series* 56: 7-30

39. Ali JR, Aitchison JC (2008) Gondwana to Asia: Plate tectonics, paleogeography and the biological connectivity of the Indian sub-continent from the Middle Jurassic through latest Eocene (166–35 Ma). *Earth-Sci Rev* 1: 145-166.

40. Tambussi CP, Degrange FJ (2013) *Paleogeographic Background, in South American and Antarctic Continental Cenozoic Birds: Paleobiogeographic Affinities and Disparities*. 2013, Springer

41. O´Dea A Hoyos N, Rodríguez F, De Gracia B, De Gracia C. (2012) History of upwelling in the Tropical Eastern Pacific and the paleogeography of the Isthmus of Panama. *Palaeogeogr Palaeoclimatol Palaeoecol* 348-349: 59-66

42. Montes C, Bayona G, Cardona A, Buchs DM, Silva CA, Morón S, Hoyos N, Ramírez DA, Jaramillo CA, Valencia V (2012) Arc-continent collision and orocline formation: Closing of the Central American seaway. *J of Geophys Res: Solid Earth* 117 (B4):B04105

43. Koufos GD, Kostopoulos DS, Vlachou TD (2005) Neogene/Quaternary mammalian migrations in Eastern Mediterranean. *Belg J Zool* 135(2): 181-190

44. van der Made J (1999) Intercontinental relatioship Europe-Africa and the Indian Subcontinent. In Rössner G and Heissig K (eds) *The Miocene Land Mammals of Europe*. Verlag Dr Friedrich Pfeil: München. pp.359-364

45. Rögl F (1999) Mediterranean and Paratethys. Facts and Hypotheses of an Oligocene to Miocene Paleogeography. *Geologica Carpathica* 50(4): p. 339-349

46. Husemann, M. Schmitt T, Zachos FE, Ulrich W, Habel JC (2013) Palaearctic biogeography revisited: evidence for the existence of a North African refugium for Western Palaearctic biota. *J Biogeogr* 1:1-14

47. Ogasawara, K (1998) Review and comments on late Neogene climatic fluctuations and intermittence of Bering Land Bridge. *J Asian Earth Sci* 16(1):45-48

48. Marincovich L, Gladenkov AY (1999) Evidence for an early opening of the Bering Strait. *Nature* 397(149-151): 149

49. Marincovich L, Gladenkov AY (2001) New evidence for the age of Bering Strait. *Quat Sci Rev* 20: 329-335

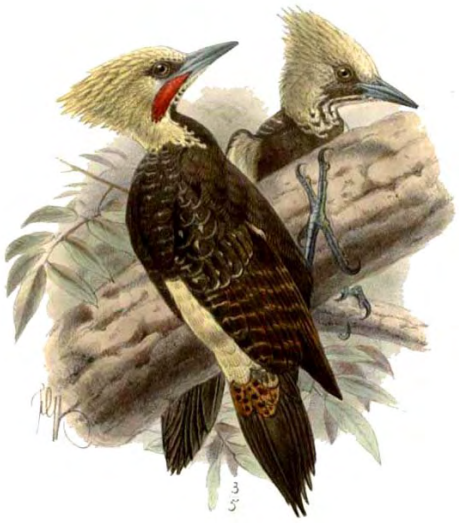
50. Duque-Caro H (1990) Neogene stratigraphy, paleoceanography and paleobiogeography in northwest South America and the evolution of the Panama Seaway. *Palaeogeogr Palaeoclimatol Palaeoecol* 77: 203-234

51. Schmittner A, Sarnthein M, Kinkel H, G. B, Bickert T, Crucifix M, et al. (2004) Global impact of the Panamanian Seaway closure. *Eos* 85(49): 526-528

52. Fortunato H (2008) The Central American land bridge: evolution at work. *Schriften des Naturwissenschaftlichen Vereins für Schleswig-Holstein*, 70: 56-72

53. Webb D (2006) The Great American Biotic Interchange: Patterns and Processes. *Ann Mo Bot Gard* 93(2): 245-257

54. Montes C, Cardona A, Jaramillo CA, Pardo A, Silva J, Valencia V, Ayala C, Pérez-Angel L, Rodríguez-Parra L, Ramírez V (2015) Middle Miocene closure of the Central American Seaway. *Science* 348 (6231):226-229



4 Phylogeny and biome occupancy

A phylogenetic perspective on bird occupation and adaption: Galliformes and Falconiformes as contrasting cases

4

"…By far, the most remarkable feature in the natural history of this archipelago… is that the different islands to a considerable extend are inhabited by a different set of beings."

Charles Darwin, *the Voyage of the Beagle* **(1839)**

"The extreme clarity of the desert light is equalled by the extreme individuation of desert life forms..."

Edward Abbey, *Desert solitaire* (1968)

ABSTRACT

The influence of historical climatic and geological events on evolutionary dynamics of birds at broad scale has been studied under different points of view. However, the integration of diverse evolutionary hypotheses related with their ecological specialization and cladogenesis are still incomplete. In this sense, biomes are key ecological units that integrate climatic variables, current landscapes and particular histories linked to geologic processes, which configures specific biotas in constant evolution. These features consolidate the biomes as "evolutionary scenarios" with their own diversification dynamics. According to this, what environmental factors

would be determinant in the colonization of the different biomes through time by clades originating in other biomes? We assess ancestral biome occupancy under the phylogenetic niche conservatism concept, which will allow us to analyse geographic distribution patterns and adaptation to different climate regimes. These aspects are fundamental to understand the underlying dynamic of subsequent diversification in each biome. In this work, we reconstructed the biome colonization history of two clades of birds: Galliformes and Falconiformes. These groups show different trophic characteristics, which allowed us to assess the effect of diet in their evolutionary patterns. Overall, our findings for both groups are broadly consistent with a scenario of phylogenetic biome conservancy and highlight the significant importance of global climate changes during the Miocene in the adaptation and evolution of climate niche in both groups. Finally, the historical dynamics of dry and seasonal biomes such as tropical deciduous woodlands and savannas have a preponderant role in the diversification of these groups.

Keywords: Ancestral Biome occupancy, Cenozoic, Climate niche evolution, Macroevolution, Neogene, Phylogenetics.

4.2. INTRODUCTION

Biomes have acquired a broad relevance as analytical units in macroecological and macroevolutionary studies on the connection between climatic gradients and vertebrate diversity gradients (Hawkins et al. 2003; Pennington et al. 2004a; Crisp 2006; Crisp et al. 2009; Jetz and Fine 2012; Cantalapiedra et al. 2014). The biome concept integrates the biotic assemblage and a varied series of abiotic conditions, mainly based on mean annual values of different climatic variables (Walter 1970; Whittaker 1975; Strahler and Strahler 1987). The confluence of these factors configures a determinate climate regime, which favours a specific plant physiognomy (Holdridge 1967; Walter 1970; Whittaker 1975; Woodward et al. 2004; Donoghue 2008; Donoghue and Edwards 2014). The particular features of each biome and their own geological and climatic history may favour a novel understanding of the relationship between diverse taxa including historical biome dynamics and the configuration of evolutionary processes, patterns of diversification and colonization of new environments at global scale (Jansson 2003; Guerrero et al. 2013; Giarla and

Jansa 2014; Davies et al. 2011; Cantalapiedra et al. 2011; Toussaint et al. 2012; Cantalapiedra et al. 2014).

Biomes differ in origin age and have suffered many geographic fluctuations during the Cenozoic (Potts and Behrensmeyer 1992; Flower and Kennett 1994; Senut et al. 2009; Jaramillo et al. 2010) due to their dependency on globally changing climates. These historical patterns can be inferred using techniques that use global climate models and paleobotanical data (Valdes 2000; Kohfeld and Harrison 2000; Harrison and Prentice 2003; Salzmann et al. 2008). In accordance with such models, during the Neogene the biomes experimented changes consistent with a global cooling and drying trend (Zachos et al. 2001; Salzmann et al. 2008; Pound et al. 2012). In this context, different biomes have exhibited different geographic dynamics (contraction, fragmentation-expansion and generation of new environments), creating diverse evolutionary scenarios (Vrba 1992, 1995; Hernández Fernández and Vrba 2005; Jetz and Fine 2012; Donoghue and Edwards 2014).

According to the environmental niche conservatism hypothesis, the species tend to preserve and share ancestral adaptive and ecological traits adjusted by phylogenetic constraints (Peterson et al. 1999; Wiens 2004; Wiens et al. 2010). Specific environmental conditions might promote the development of physiological traits to cope adverse conditions in many climate regimes that requires highly specialized functional features and requirements (Janzen 1967; Ghalambor et al. 2006). Conversely, a high versatility level in relation to resources and climatic conditions could *a priori* enable a prominent capacity to colonize and occupy diverse habitat types (Jocque et al. 2010; Salisbury et al. 2012; Pigot and Tobias 2013, 2015). This could explain how, despite phylogenetic niche conservatism, many clades had succeed in the colonization of new available habitats as new biomes evolved (Guerrero et al. 2013). In many cases, paleoclimatic shifts might have promoted environmental flexibility by expansion of the climatic tolerance (Guerrero et al. 2013; Jara-Arancio et al. 2014). This process depends on genetic variation of species populations, which allows them to broaden their climatic niche and to colonize new environments.

The integration of niche conservatism theory and the biome concept generates a macroevolutionary context where the biome conservatism might has an important role for explaining the global latitudinal gradient of species richness (Crisp et al.

2009). This conceptual framework also constitutes a key to recognize the mode and tempo of climatic niche evolution by developing of adaptations in the phylogenetic history of taxa to invade a novel environment (Crisp et al. 2009; Guerrero et al. 2013; Jara-Arancio et al. 2014; Donoghue and Edwards 2014). The process of biome colonization may provide valuable information about possible morphophysiological constraints or the ecological and climatic versatility that would permit adaptation to adverse biomes such as the desert or tundra.

Birds are good indicators for macroevolutionary and macroecological studies due to their well-known biogeography, great diversity and relative well-established phylogenies (Jetz et al. 2012; Jarvis et al. 2014). In this study, we analysed the pattern of biome occupancy and their conservatism in Galliformes and Falconiformes in relation with past climatic changes and geological processes that could have influenced their evolution and adaptation to specific climatic regimes. Both taxa present broad global distributions and inhabit all the world's biomes. In addition, these groups have a distinctive ecology occupying different trophic positions, both herbivorous and faunivorous. Finally, our analysis of biome occupancy under phylogenetic perspective in these bird groups allows integrating the influence of diverse climatic and geological events with the biomes colonization processes, which allow us to evaluate the biome conservatism tendencies and understand the importance of the different biomes in the diversification processes in both taxa.

4.3. MATERIALS AND METHODS

4.3.1. Studied taxa and phylogenetic information

The order Galliformes (landfowl and allies) holds 289 extant species, all of them with predominantly herbivorous diet (Del Hoyo et al. 1992). In addition to their environmental variability, Galliformes exhibit a broad body size range, from the relatively small common quail (*Coturnix coturnix*, near 35g) to the wild turkey (*Meleagris gallopavo*, about 5kg). The phylogenetic relationships of the Galliformes are among the best known within birds. Phylogenetic hypothesis for the group was initially based on morphological data and has been updated recently with the implementation of molecular techniques (Eo et al. 2009; Kimball et al. 2011; Hugall and Stuart-Fox 2012; Wang et al. 2013; Stein et al. 2015). This monophyletic group

is divided in five families: Megapodidae (brush-turkeys and scrubfowls), Cracidae (curassows and guans), Numididae (guineafowls), Odontophoridae (New World quails) and Phasianidae (pheasants, Old World quails, grouses and turkeys). Nevertheless, there is no complete phylogeny at the species level for this order yet. For this reason we built an informal dated supertree that integrates 77.8 % of the species (225 species) taking into account the most complete calibrated phylogenies published to this date (Hugall and Stuart-Fox 2012; Stein 2013; Wang et al. 2013; Stein et al. 2015). For taxonomic consistency, the nomenclature for the consensus tree was adapted according to Del Hoyo and Collar (2014).

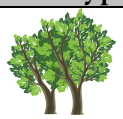
The order Falconiformes (falcons and allies) includes 66 species classified within the family Falconidae (Fuchs et al. 2012; Del Hoyo and Collar 2014; Fuchs et al. 2015). Overall, falcons are faunivorous with a body size spectrum from small species such as black-thighed falconet (*Microhierax fringillarius*, 35 g) to the gyr falcon (*Falco rusticulus*, 1.7kg) (Ferguson-Lees and Christie 2001). Ecologically, falcons have a great variety of habitat preferences that includes forest, savanna, desert and steppes; many species show a wide spectrum of environmental occupation as in the case of peregrine falcon (*Falco peregrinus)* with a worldwide distribution. Considering their phylogenetic relationships, two subfamilies are well established: Herpetotherinae (laughing and forestal falcons) and Falconinae (caracaras, falconets, falcons and kestrels). We employed the most complete falcon phylogeny published recently by Fuchs et al. (2015), which includes all the species. To conserve the taxonomic consistence, we used Del Hoyo and Collar (2014).

4.3.2. Biomes selection and occupation data

We selected the biome classification system developed by Walter (1970) and modified by Hernández Fernández (2001), which establishes ten biomes considering the annual relative distribution of temperature and precipitation (Table 1). Paleoclimatic studies reveal diverse variation in the age and spatial dynamic of the biomes (Pennington et al. 2004a; Jetz and Fine 2012). The oldest biomes —such as evergreen tropical rainforest— have been reported since the Cretaceous and Paleocene (Davis et al. 2005; Jaramillo et al. 2010; Jaramillo 2012; Jaramillo and Cárdenas 2013). Successively during the Eocene, with the climatic fluctuations of rainforest appeared areas of tropical deciduous woodland and savanna (Bredenkamp et al. 2002; Jacobs 2004; Pennington et al. 2004a; Jaramillo and Cárdenas 2013),

4. Phylogeny and biome occupancy

Table 1. Biomes structure and age (f: forest environments; o: open environments)

Biome	Biome type	Age of origin	References
Evergreen tropical rainforest (I)	 (f)	Late Cretaceous – Paleocene	(Jaramillo et al. 2010; Jaramillo 2012; Davis et al. 2005)
Tropical deciduous woodland (II)	 (f)	Early Eocene (small areas) Early Oligocene (Cover large areas)	(Pennington et al. 2004; Jacobs 2004; Werneck et al. 2011)
Savanna (II/III)	 (o)	Early Eocene (small areas) Late Miocene (cover large areas)	(Jacobs 2004; Pennington et al. 2004; Beerling and Osborne 2006)
Subtropical desert (III)	 (o)	Early Oligocene (small areas) Pliocene (cover large areas)	(Shmida 1985; Senut et al. 2009; Guerrero et al. 2013)
Sclerophyllous woodland-Shrubland (IV)	 (f)	Late Miocene (small areas) Plio-Pleistocene (cover large areas)	(Hernandez Fernandez et al. 2007; Buerki et al. 2012; Pennington et al. 2004)
Temperate evergreen forest (V)	 (f)	Early Eocene	(Markgraf et al. 1995; Fine and Ree 2006; DeVore and Pigg 2013)
Broadleaf deciduous forest (VI)	 (f)	Early Eocene	(Markgraf et al. 1995; Fine and Ree 2006; DeVore and Pigg 2013)
Steppe to cold desert (VII)	 (o)	Early Miocene (small areas) Plio-Pleistocene (cover large areas)	(Axelrod 1985; Janis 1993; Zimov et al. 1995; Franzke et al. 2004; Wang 2004; Kahlke 2014)
Boreal coniferous forest (VIII)	 (f)	Middle-Late Miocene	(DeVore and Pigg 2013; Fine and Ree 2006; Pound et al. 2011)
Tundra (IX)	 (o)	Plio-Pleistocene	(Zimov et al. 1995; Kahlke 2014)

which extended broadly during the Oligocene and Late Miocene respectively (Pennington et al. 2004b; Edwards et al. 2010). Likewise, during the Eocene emerged temperate evergreen forest and broadleaf deciduous forest biomes in high-latitude zones (Axelrod 1966; Markgraf et al. 1995; DeVore and Pigg 2013). During the middle-late Miocene, after the Mid-Miocene Climate Optimum, the drop of temperature gradients triggered the increase of aridity conditions (Zachos et al. 2001). These factors promoted the origin of boreal coniferous forest in highest latitudes (Wolfe 1985; Pound et al. 2011; Popova et al. 2012). Meanwhile, other more open biomes such as savannas, steppes and deserts began to expand in the drier and arid areas (Axelrod 1985; Bredenkamp et al. 2002; van Dam 2006; Byrne et al. 2008; Senut et al. 2009; Guerrero et al. 2013). Along the Pliocene and Pleistocene diverse extreme climatic events caused phases of icehouse and subsequent glaciations, which propitiated the emergency of biomes such as sclerophyllous woodland-shrubland (Hernandez Fernandez et al. 2007; Buerki et al. 2012) and tundra polarwards (Wolfe 1985; Zimov et al. 1995; Hewitt 2003). Moreover, this period implied the prominent expansion of steppes in high latitudes (Franzke et al. 2004; Kahlke 2014) and deserts in subtropical latitudes (Bobe 2006; Senut et al. 2009) with the opposite effect of area contractions of tropical and wet biomes (Hooghiemstra and Van der Hammen 2004; Jaramillo and Cárdenas 2013; Raes et al. 2014).

The biome occupation of each species was determined following the methodology developed by Hernández Fernández (2001). According with the geographic information for the distribution of each species, we codified the presence or absence of species in each biome considering the relative size of its geographical range. If 15% or more of the species geographical range is situated within a specific biome, the species is considered to occupy that biome. For the case of biomes with relative small areas respect to the species geographical range, we also recorded the presence of species when the species inhabits 50% or more of one climatic dominion. The species with presence in mountain environments were registered as presence in correspondence with the analogous biome considering the altitudinal climatic gradient.

4.3.3. Ancestral biome reconstruction

For reconstructing ancestral biome occupations we modelled the occurrence of species in the ten biomes along the evolutionary history of Galliformes and

Falconiformes using a phylogenetic approach. The ancestral biome occupation for all lineages was estimated through maximum likelihood analysis of geographic range evolution using the package BioGeoBEARS (BioGeography with Bayesian and Likelihood Evolutionary Analysis) implemented in R (Matzke 2013). This analysis allowed us to model the dynamics of biome occupation in relation to the timing of cladogenesis based on the splitting times of the phylogenetic trees. Although it was originally designed for the study of biogeographic evolution, BioGeoBEARS is an analytic approximation that allows probabilistic inference of ecological characters, biome occupation in our case, integrating different models onto a time-calibrated phylogenetic tree (Batalha-Filho et al. 2014; Alfaro et al. 2015; Buckner et al. 2015; Mendoza et al. 2015; de Medeiros and Lohmann 2015). This tool enabled us to infer the ancestral biome in each node along the phylogeny. BioGeoBEARS estimates maximum likelihood for ancestral states during speciation events modelling the transitions between different states (biomes occupied) along the phylogenetic branches as a function of time. The analyses were conducted using the dispersal-extinction-cladogenesis model (DEC) (Ree and Smith 2008), modified in BioGeoBEARS with the new parameter *j* (for *jump*)(Matzke 2014a; Matzke 2014b). The analyses took into account the adjustment of the specific parameters for the evolutionary model (d=dispersal and e= extinction) and the novel parameter *j*, which models the process of founder-event speciation (Matzke 2014a). Due to evolutionary biome dynamic, we configured a BioGeoBEARS supermodel with freedom the parameters of DEC-j analyses, respect to the effect of specific and diverse dispersal capacities within the families that allow differential probabilities of biome colonization by the long-distance mechanisms (Price and Clague 2002; Pigot and Tobias 2015).

Processes of climate change have altered the ecological conditions of the earth over geologic time. This has leaded to different biomes having particular histories in relation with their origin and processes of geographic fluctuation. Considering this, for the DEC-j analysis we included a "biome existence matrix", which incorporates information about the availability of each biome along the Cenozoic. In this way, we introduced temporal constraints related to the geological, climatic and ecological history of biomes in the analysis. Likewise, due to the diverse points of view regarding the extent and age of the biomes, the opinion respect of their origin in small areas present more uncertainly and diverse interpretations (Jetz and Fine

2012). Thus, when building the biome availability matrix, we considered origin-age estimates based on robust fossil and geological evidence (Table S1, Appendix 4.8).

We also established a "biomes connection matrix", which allows the inclusion of changing dispersal probabilities between biomes across the temporal span of the analyses. This was constructed based on climatic and geographical information of biomes in relation to all non-passerine birds (3951 spp) observed occupation (Chapter 1) with near 239 biome combinations (Table S2 in Appendix 4.8). These 239 combinations represent the biologically possible connection between biomes in order to avoid the computational intractability of the analysis with all combinations (1023) (Hernández Fernández and Vrba 2005; Matzke 2013).

The reconstruction process of ancestral biome occupancy combines all the information (living species biome occupation, the tree topology, the availability and the connections among biomes through time) and yields the likelihood values for each biome combinations in each node. BioGeoBEARS output for ten-areas analyses is complex. In order to organize the results and obtain the general patterns of historical biome occupation, we established a criterion based in the selection of the biome configurations with highest probability results for each node, which were organized decreasingly according to their likelihood value. The probability scores for these biome combinations were cumulative until a value of 0.5 was reached. The relative likelihood scores of each biome within these combinations were summed and all biomes with a cumulative likelihood of more 0.25 were retained for each node (Tables S3, S4). For example, if for a node the most probable biome combinations are I-II (presence in evergreen tropical rainforest and tropical deciduous woodland) with a likelihood value of 0.4, and II-II/III (presence in tropical deciduous woodland and savanna), with 0.12, this would imply that the values of relative probability for each biome are defined as follows: I=0.4, II=0.52 and II/III=0.12. We would then consider that only biomes I and II are robustly reconstructed for that particular node.

With the results for biome occupation in each node of the tree (Fig.1, Fig.4), we described the occupation trends of the different biomes through time. In order to assess the phylogenetic biome conservatism tendencies for both groups, we counted the transitions between biomes from each node to its descendant nodes. We then evaluated the relationship between historical biome dynamics and the development of new climatic niche by adaptation in the evolution of the lineages.

In order to explore the biome colonization dynamics in each biome, we established the colonization events that explain the nodes states along the branches of the tree. However, the transition events have a temporal uncertainty, which is proportional to the branch length. Likewise, the phylogenies present a trend to increase the amount of branches along time producing an important bias towards present. To solve these issues, we analysed the biome colonization through time using a *sliding window* method. This approach was employ to calculate the mean and the confidence interval of colonization rates in each biome considering 1 million years time intervals and smoothed with a 5 million years sliding window that includes a correction factor taking into account the number of branches during each time bin (Vieites et al. 2007; Meredith et al. 2011).

4.4. RESULTS

4.4.1. Ancestral Biome occupancy reconstruction in Galliformes

Our analysis reconstructed ancestral biome occupancy for 220 nodes (98.21%); the remaining 4 nodes presented low statistical support for any of the ten biomes (Table S3). The common ancestor of the Galliformes was associated during the Late Eocene with tropical rainforest, tropical deciduous forest, savanna and temperate evergreen forest biomes (Fig.1). According to the results for biome occupancy patterns in Galliformes, this lineage presented three main moments of diversification: First, since early to middle Miocene, Phasianidae family presented an important radiation associated mainly with tropical deciduous forest. Likewise, during this period was recorded an important colonization of broadleaf deciduous forest, which allow then the subsequent colonization of temperate and cold biomes; secondly, along the Late Miocene the fowl tropical families Megapodiidae, Numididae, Cracidae and Odonthophoridae experimented a prominent process of diversification in Australasia, Afrotropics and Neotropics respectively. Despite their isolation, showed a close relationship with tropical deciduous forest, savannas and temperate evergreen forest. Conversely, some phasianid lineages (Tetraonini) radiated colonizing new cold biomes such as taiga. Finally, along the Plio-Pleistocene, Galliformes lineages reached their higher radiation and especially phasinidae species entered diverse emerging and extending biomes during glaciation periods such as sclerophyllous woodland-shrubland, deserts and steppes (Zimov et al. 1995; Douglas et al. 2006; Senut et al.

2009). Other biomes as evergreen rainforest and temperate evergreen forest also increased their number of invasions possibly because of the fragmentation and expansion that underwent during the glacial periods (Jaramillo et al. 2006; Werneck et al. 2011; Jaramillo 2012; Raes et al. 2014; Woodruff 2010).

Considering families (Fig.1), Megapodidae showed an ancestral biome occupation within the tropical deciduous forest and savanna, while Cracidae presented an ancestral occupation associated with tropical deciduous forest and temperate evergreen forest. It is interesting the differentiation pattern in two main clades of Cracidae, which reflected trends in the climate niche evolution towards temperate evergreen forest in the case of the subfamily Penelopinae and tropical deciduous forest in the clade that contains the rest of subfamilies. Ancestral biome for Numididae reflected an early occupation of savannas. The reconstruction for Odontophoridae showed an uncertain state for the ancestral biome occupation and two unresolved nodes inside the family. This result was probably due to the incomplete knowledge of phylogenetic relationships within this family, especially in *Odonthophorus*, which impeded the inclusion of climatic information for all species. However, our results showed a clearly differentiation in the principal lineages with species radiated towards two climate niches associated with tropical deciduous forest and temperate evergreen forest biomes.

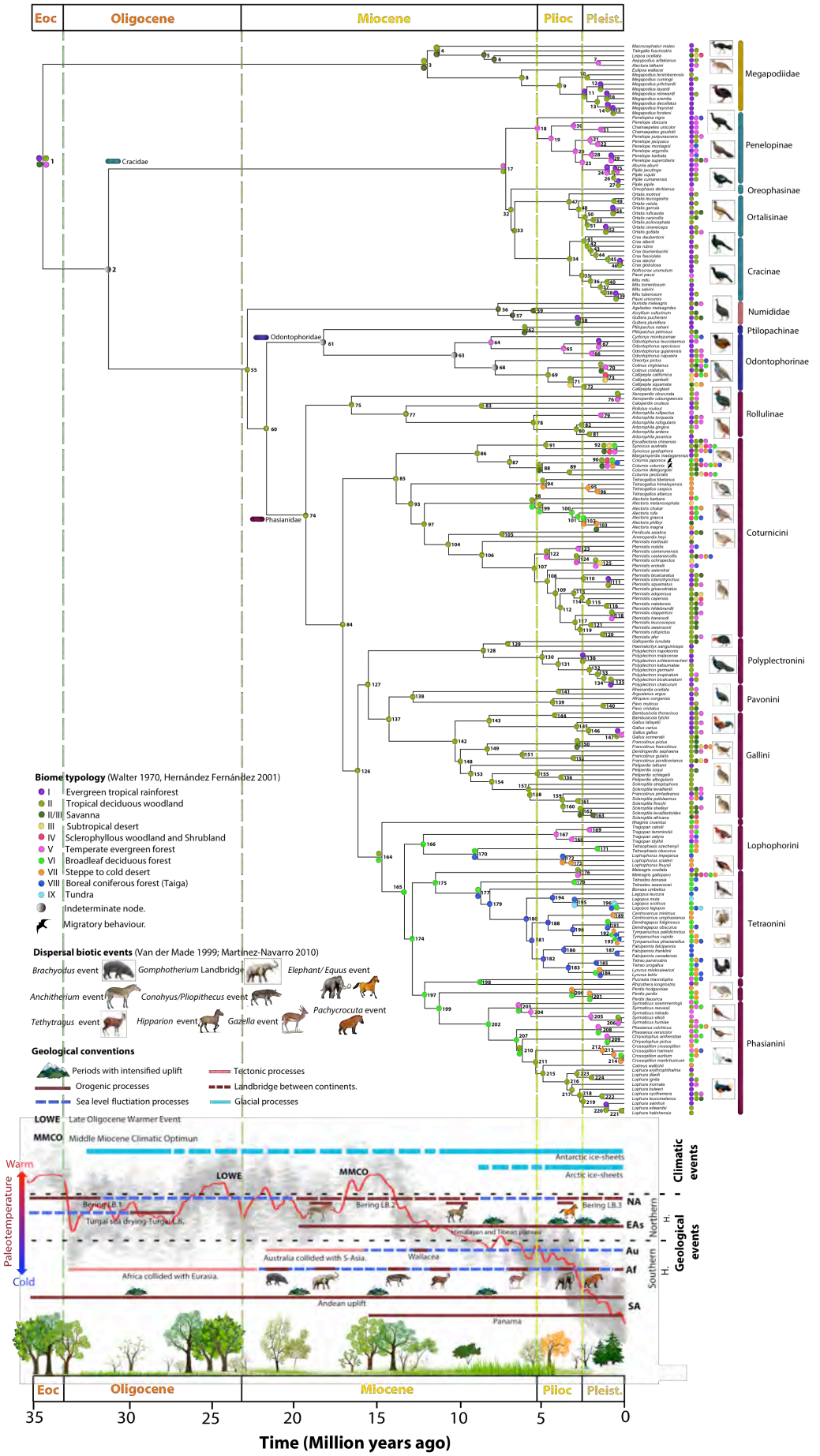
Finally for the most specious Phasianidae, we found an ancestral biome occupation of tropical deciduous woodland and early diversification during the middle Miocene associated with this biome (Fig.1). Tropical deciduous woodland was ancestral biome of subfamily Rollulinae from Southeast Asia. Meanwhile, several tribes of Phasianinae (Coturnicini, Polyplectronini, Pavonini and Gallini) with an important geographical distribution in Africa and Asian Southeast also showed a diversification pattern within tropical deciduous forest, which is conserved along many clades of Phasianinae. Likewise, during the middle Miocene one lineage of phasianids would reach to colonize the temperate broadleaf deciduous forest. Within this lineage, the tribe Tetraonini ancestors entered in the boreal coniferous forest during the late Miocene. This group showed important biome conservatism associated with the taiga biome during its radiation. Other lineages such as Lophophorini independently occupied the boreal coniferous forest at the same moment that Tetraonini. On the other hand, Phasianini tends to preserve the

ancestral biome occupation in the broadleaf deciduous forest with subsequent colonizations of temperate evergreen forest and tropical deciduous forest (Fig.1).

According with the general tendencies, the results suggest different phases of biome colonization (Fig.2); during the early Oligocene the tropical deciduous woodland and the temperate evergreen forest presented an outstanding growing. In the Oligocene-Miocene boundary, the savanna registered an increase of new species. Meanwhile, the rates of colonization decrease in tropical deciduous woodland and the temperate evergreen forest during the same period. Later, along the middle and late Miocene we evidenced a marked growth in the colonization rates for the majority of biomes. Biomes such as evergreen tropical rainforest experimented a prominent increase of colonizations until the Pleistocene. Furthermore, emerging biomes such as deserts, sclerophyllous woodland-shrubland, steppe and taiga, represented new ecological opportunities for novel lineages. The new but limited niches probably allowed early increase of colonization events with subsequent stabilization as was observed for many seasonally biomes in boreal and subtropical latitudes.

Transitions among biomes are shown in Fig.3. We found important support for phylogenetic biome conservatism in the evolution of Galliformes. Biome occupancy was conserved along the phylogeny in 475 of 767 transition events (61.92%) while the biome shifts were represented by 292 possible invasion events (38.07%) (Table 2, Fig.3). The frequency of transitions between biomes reflects a higher signal of biome conservatism (%BC). All the biomes, except the savanna and sclerophyllous woodland-shrubland, presented values for biome conservatism higher than 50% with more elevated values (>75%) associated with biomes occupying the climate extreme gradient: evergreen tropical rainforest (82.93%), steppe (83.78%) and tundra (100%)(Table 2). The directional patterns in transition among biomes showed a predominant bias, with the tropical deciduous woodland as net species source for other biomes in tropical and subtropical latitudes.

Figure 1. Ancestral biome reconstruction for Galliformes. The colors represent the 10 different biomes implemented in the model (Walter 1970, Hernández Fernández 2001). For each node, the colored circle represents the inferred biome (s) on all the nodes. The colors in the tips correspond with the recent biome distribution of species. Along the time scale, geological and climatic histories are shown as well as intercontinental biotic interchanges. LB: Landbridge; NA: North America; EAs: Eurasia; Au: Australia; Af: Africa; SA: South America.


Eoc
Oligocene
Miocene
Plioc
Pleist.
Cracidae
Odontophoridae
Phasianidae
Megapodiidae
Penelopinae
Oreophasinae
Ortalisinae
Cracinae
Numididae
Ptilopachinae
Odontophorinae
Rollulinae
Coturnicini
Polyplectronini
Pavonini
Gallini
Lophophorini
Tetraonini
Phasianinini
Biome typology (Walter 1970, Hernández Fernández 2001)
I Evergreen tropical rainforest
II Tropical deciduous woodland
II/III Savanna
III Subtropical desert
IV Sclerophyllous woodland and Shrubland
V Temperate evergreen forest
VI Broadleaf deciduous forest
VII Steppe to cold desert
VIII Boreal coniferous forest (Taiga)
IX Tundra
Indeterminate node.
Migratory behaviour.
Dispersal biotic events (Van der Made 1999; Martínez-Navarro 2010)
Brachyodus event
Gomphotherium Landbridge
Elephant/ Equus event
Anchitherium event
Conohyus/Pliopithecus event
Pachycrocuta event
Tethytragus event
Hipparion event
Gazella event
Geological conventions
Periods with intensified uplift
Tectonic processes
Orogenic processes
Landbridge between continents.
Sea level fluctiation processes
Glacial processes
LOWE Late Oligocene Warmer Event
MMCO Middle Miocene Climatic Optimun
Warm
Cold
Paleotemperature
LOWE
MMCO
Antarctic ice-sheets
Arctic ice-sheets
Climatic events
Beringel LB.1
Turgai sea drying-Turgai L.B.
Bering LB.2
Bering LB.3
NA
EAs
Northern H.
Himalayan and Tibetan plateau
Australia collided with S-Asia.
Wallacea
Au
Af
Southern H.
Geological events
Africa collided with Eurasia.
Andean uplift
SA
Panama
Eoc
Oligocene
Miocene
Plioc
Pleist.
35
30
25
20
15
10
5
0
Time (Million years ago)

4. Phylogeny and biome occupancy

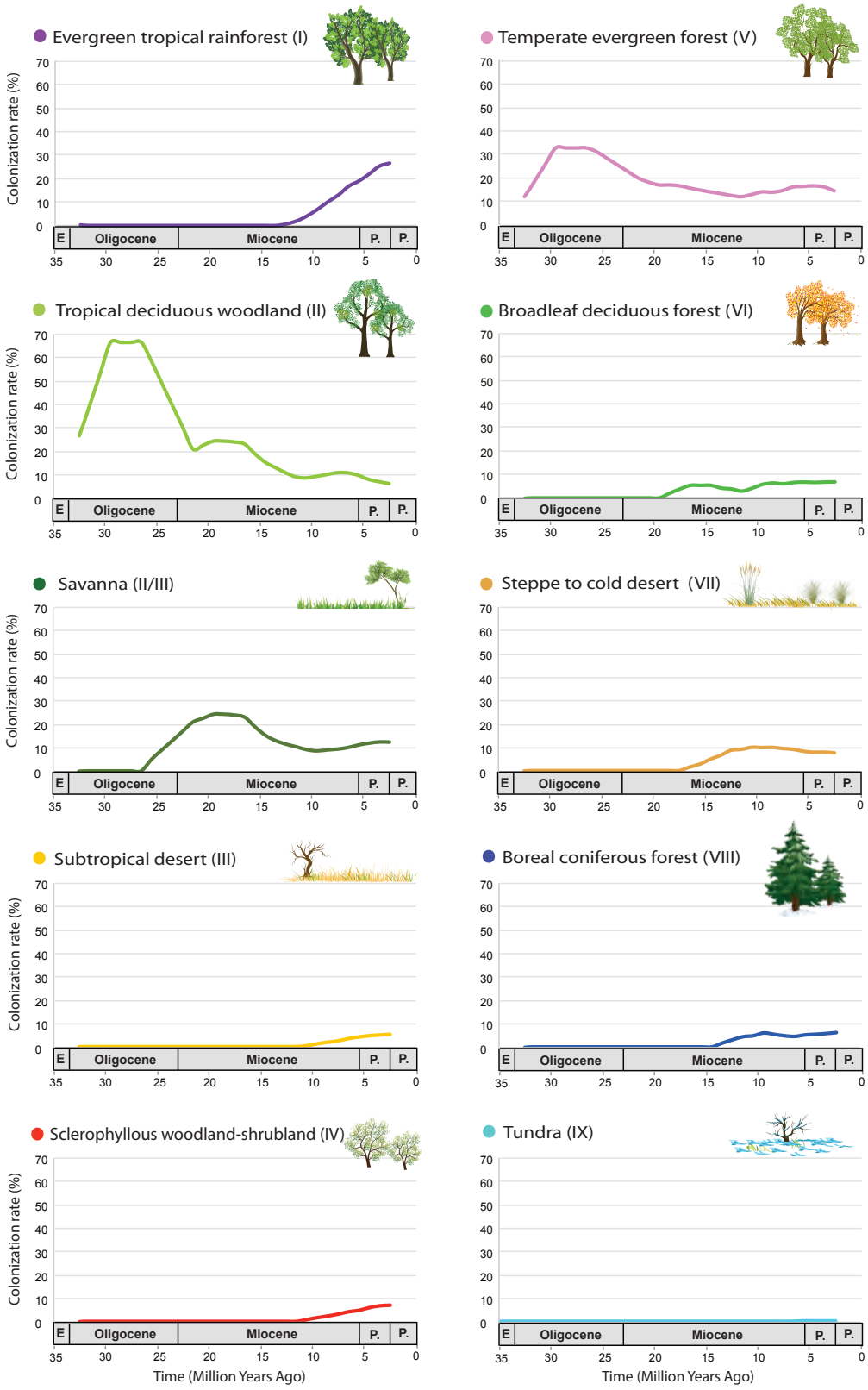


Figure 2. Colonization dynamics of Galliformes. For each biome is represented the rate of colonization by new lineages along the geologic time.

4. Phylogeny and biome occupancy

Table 2. Biome transitions in Galliformes

BIOME	Destination											
Source	I	II	II/III	III	IV	V	VI	VII	VIII	IX	Total col.	% BC
I	**34**	4	1			2					7	**82.9**
II	55	**225**	34	10	7	29	7	7			149	**60.2**
II/III	7	5	**23**	2	4	3	2	4			27	**46.0**
III				**5**	1		1	2			4	**55.6**
IV					**3**		1	3	1		5	**37.5**
V	20	13	3		1	**67**	5		10		52	**56.3**
VI		3		1	4	4	**54**	10	6		28	**65.9**
VII					1		1	**31**	4		6	**83.8**
VIII							7	6	**30**	1	14	**68.2**
IX										**3**	0	**100.0**

Number of biome transitions for each biome considering the source (rows) and destination (columns). Bold numbers along the diagonal show transitions with no change of biome (**475**). Total col. on the right indicates the transitions that imply colonization (**292**). % BC, represents the proportion of biome conservatism for each biome according to colonization tendencies. The total number of transitions was **767**.

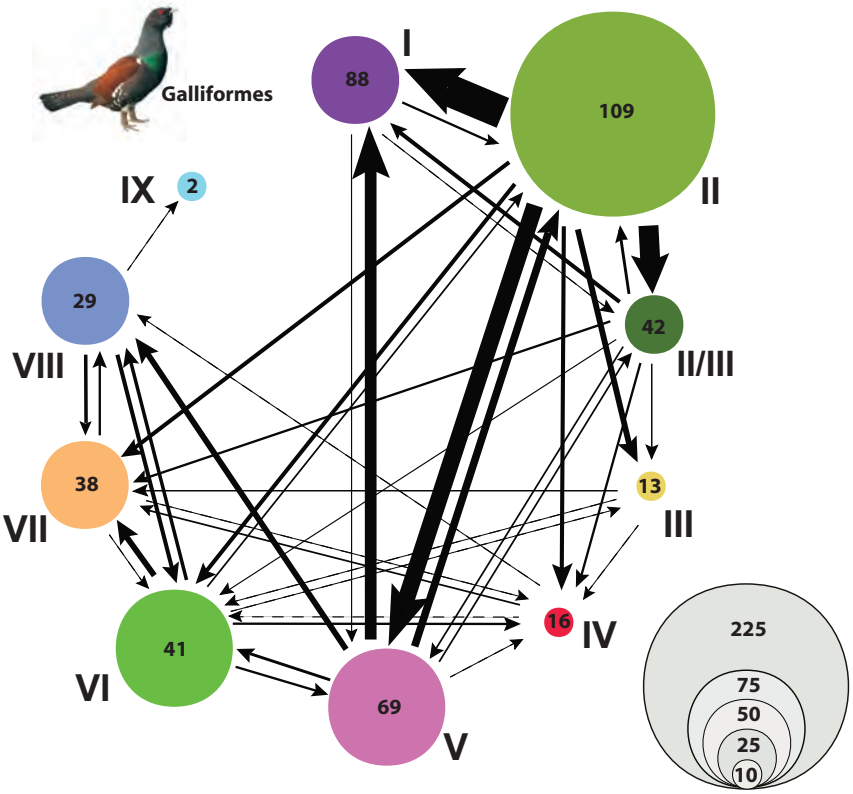


Figure 3. Biome transitions in Galliformes. Number of recent species is indicated inside the circle. Arrow thickness is proportional to the number of colonizations, the dashed lines indicate only one colonization event. The number of transitions that not implied colonization is indicates as different ranges in the circles area classified in five categories (see diagram). For more details about absolute scores see Table 2.

4.4.2. Ancestral Biome occupance reconstruction in Falconiformes

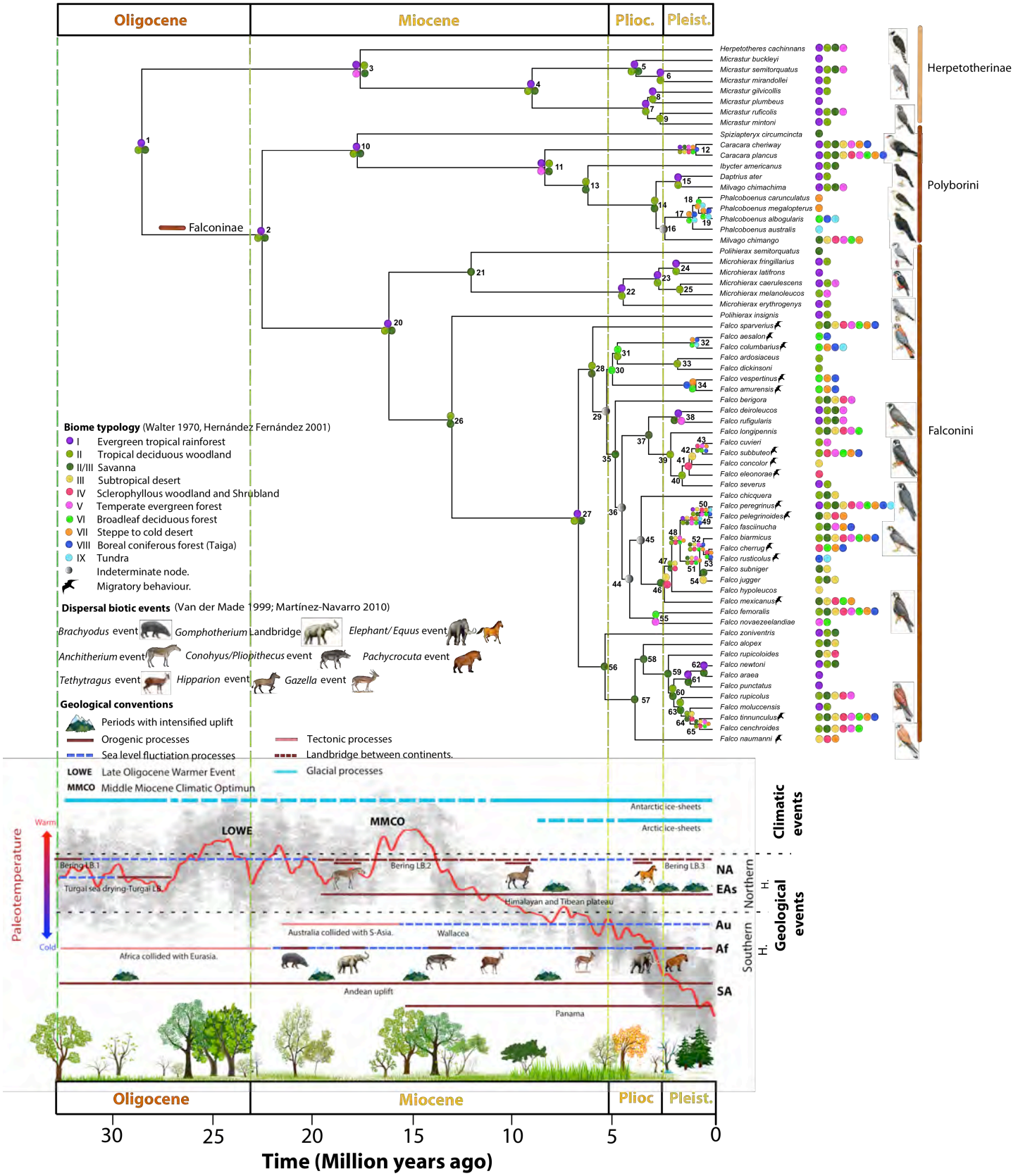
We reconstructed the ancestral biome occupancy for 60 of 65 (92.31%) nodes in the phylogenetic tree of Falconiformes (Table S4, Fig.4). Our findings suggest that the early Oligocene ancestor of falcons probably occupied environments associated with tropical biomes such as evergreen tropical rainforest, tropical deciduous woodland and savannah (Fig.4). During lower and middle Miocene the Falconiformes basal lineage (Herpetotherinae) extended towards temperate evergreen forest, but conserved the association with forested tropical biomes and savanna. Finally, along the Pliocene this lineage diversified into the tropical rainforest and deciduous forest. Poliborini and Falconini diverged during the middle Miocene conserving the ancestral biome occupancy. Our results indicate an initial colonization from tropical biomes to temperate environments by Poliborini ancestors during the late Miocene with a subsequent specialization towards tropical seasonality and drier environments as tropical deciduous forest and savanna along the late Miocene and Pliocene; Poliborini tended to develop a generalist spectrum with broad biome occupancy in the Pleistocene. The divergence within Falconini appears to be related to the *Falco* colonization process of savannas and tropical deciduous woodlands during the middle Miocene, while *Microhierax* and *Polihierax* ancestors specialized in savanna environments. Subsequently *Falco* expands from tropical forest environments and savannas towards temperate biomes since the late Miocene (Fig.4). During the late Miocene and Pliocene there was a high speciation in falconid lineages, more highlighted in *Falco*, which was mainly associated with tropical deciduous forest and savannas. During the Pliocene falcons colonized biomes such as broadleaf deciduous forest. Likewise, along the Plio-Pleistocene also were colonized novel and emerging biomes such as desert, sclerophyllous woodland-shrubland and steppe.

In general terms, the patterns of biome colonization along time in Falconiformes (Fig.5) showed low trends in the colonization of new biomes during their early evolution in the Oligocene and early Miocene. In this period only was colonized the temperate evergreen forest. It would be later, during the middle Miocene when the falconid lineages began to colonize tropical biomes such as evergreen tropical rainforest and tropical deciduous woodland. During late Miocene, began an outstanding process of colonization in all biomes.

4. Phylogeny and biome occupancy

The results for biome transitions pattern in Falconiformes (Table 3, Fig.6) showed similar values for biome conservatism respect to Galliformes. The biome was conserved in 273 of 436 (62.61%) possible biome transitions during cladogenesis events. Meanwhile 37.39% corresponds to 163 new biome colonization events (Table 3, Fig.6). The obtained frequencies of transitions between biomes showed a significant proportion of biome conservatism with respect to the invasion of new environments. In the case of Falconiformes, all the biomes presented higher values of biome conservatism (%BC), which were higher than 50%. The highest scores were registered for biomes such as evergreen tropical rainforest (82.5%), steppes (77.8%), taiga (93.8%) and tundra (87.5%). These results also showed a prominent directional bias in the transitions among biomes, the outcomes suggest an important role of tropical deciduous woodlands and savannas being net sources of species and the evergreen rainforest and temperate evergreen forest as sink. It is interesting that savanna constitutes an important destination from lineages coming from tropical deciduous woodlands (Table 3, Fig.6).

Figure 4. Ancestral biome reconstruction for Falconiformes. The colors represent the 10 different biomes implemented in the model (Walter 1970, Hernández Fernández 2001). For each node, the colored circle represents the inferred biome (s) on all the nodes. The colors in the tips correspond with the recent biome distribution of species. Along the time scale, geological and climatic histories are shown as well as intercontinental biotic interchanges. LB: Landbridge; NA: North America; EAs: Eurasia; Au: Australia; Af: Africa; SA: South America).


Oligocene
Miocene
Plioc.
Pleist.
Herpetotherinae
Polyborini
Falconinae
Falconini
Herpetotheres cachinnans
Micrastur buckleyi
Micrastur semitorquatus
Micrastur mirandollei
Micrastur gilvicollis
Micrastur plumbeus
Micrastur ruficolis
Micrastur mintoni
Spiziapteryx circumcincta
Caracara cheriway
Caracara plancus
Ibycter americanus
Daptrius ater
Milvago chimachima
Phalcoboenus carunculatus
Phalcoboenus megalopterus
Phalcoboenus albogularis
Phalcoboenus australis
Milvago chimango
Polihierax semitorquatus
Microhierax fringillarius
Microhierax latifrons
Microhierax caerulescens
Microhierax melanoleucos
Microhierax erythrogenys
Polihierax insignis
Falco sparverius
Falco aesalon
Falco columbarius
Falco ardosiaceus
Falco dickinsoni
Falco vespertinus
Falco amurensis
Falco berigora
Falco deiroleucos
Falco rufigularis
Falco longipennis
Falco cuvieri
Falco subbuteo
Falco concolor
Falco eleonorae
Falco severus
Falco chicquera
Falco peregrinus
Falco pelegrinoides
Falco fasciinucha
Falco biarmicus
Falco cherrug
Falco rusticolus
Falco subniger
Falco jugger
Falco hypoleucos
Falco mexicanus
Falco femoralis
Falco novaezeelandiae
Falco zoniventris
Falco alopex
Falco rupicoloides
Falco newtoni
Falco araea
Falco punctatus
Falco rupicolus
Falco moluccensis
Falco tinnunculus
Falco cenchroides
Falco naumanni
Biome typology (Walter 1970, Hernández Fernández 2001)
I Evergreen tropical rainforest
II Tropical deciduous woodland
II/III Savanna
III Subtropical desert
IV Sclerophyllous woodland and Shrubland
V Temperate evergreen forest
VI Broadleaf deciduous forest
VII Steppe to cold desert
VIII Boreal coniferous forest (Taiga)
IX Tundra
Indeterminate node.
Migratory behaviour.
Dispersal biotic events (Van der Made 1999; Martínez-Navarro 2010)
Brachyodus event
Gomphotherium Landbridge
Elephant/ Equus event
Anchitherium event
Conohyus/Pliopithecus event
Pachycrocuta event
Tethytragus event
Hipparion event
Gazella event
Geological conventions
Periods with intensified uplift
Orogenic processes
Sea level fluctiation processes
Tectonic processes
Landbridge between continents.
Glacial processes
LOWE Late Oligocene Warmer Event
MMCO Middle Miocene Climatic Optimun
Paleotemperature
Warm
Cold
LOWE
MMCO
Antarctic ice-sheets
Arctic ice-sheets
Bering LB.1
Bering LB.2
Bering LB.3
Turgai sea drying-Turgai LB.
Himalayan and Tibean plateau
Australia collided with S-Asia.
Wallacea
Africa collided with Eurasia.
Andean uplift
Panama
NA
EAs
Au
Af
SA
Northern H.
Southern H.
Climatic events
Geological events
Oligocene
Miocene
Plioc
Pleist.
30
25
20
15
10
5
0
Time (Million years ago)

4. Phylogeny and biome occupancy

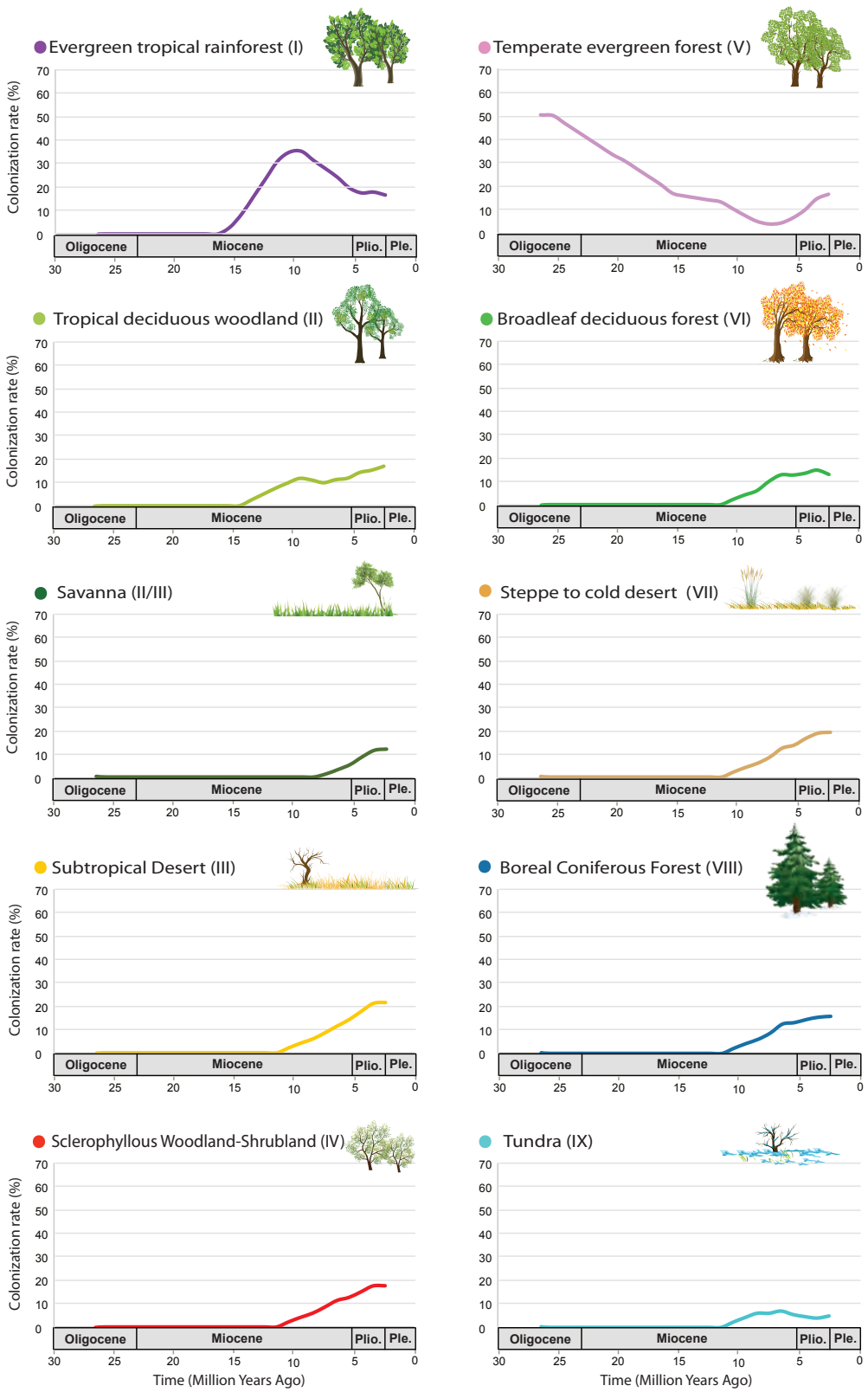


Figure 5. Colonization dynamics of Falconiformes. For each biome is represented the rate of colonization by new lineages along the geologic time.

Table 2. Biome transitions in Falconiformes

BIOME	Destination											
Source	I	II	II/III	III	IV	V	VI	VII	VIII	IX	Total col.	%BC
I	**33**	3	2			2					7	**82.5**
II	11	**61**	4	4	5	12	5	1			42	**59.2**
II/III	8	10	**57**	8	7	7	4	6			50	**53.3**
III		3		**20**	1		4	4			12	**62.5**
IV		1		1	**18**	2	3	3			10	**64.3**
V	1	3	1		1	**18**	1		6		13	**58.1**
VI		2	1	1	2	1	**23**	4	8	2	21	**52.3**
VII								**21**	5	1	6	**77.8**
VIII									**15**	1	1	**93.8**
IX									1	**7**	1	**87.5**

Number of biome transitions for each biome considering the source (rows) and destination (columns). Bold numbers along the diagonal show transitions with no change of biome (**273**). Total col. on the right indicates the transitions that imply colonization (**163**). % BC, represents the proportion of biome conservatism for each biome according to colonization tendencies. The total number of transitions was **436**.

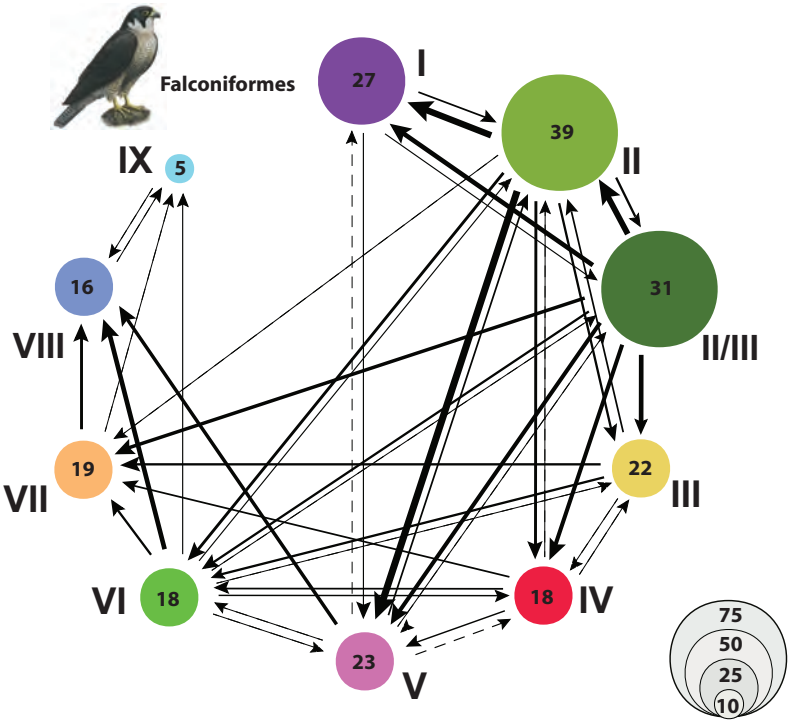


Figure 6. Biome transitions in Falconiformes. Number of recent species is indicated inside the circle. Arrow thickness is proportional to the number of colonizations, the dashed lines indicate only one colonization event. The number of transitions that not implied colonization is indicates as different ranges in the circles area classified in four categories (see diagram). For more details about absolute scores see Table 3.

4.5. DISCUSSION

4.5.1. Galliformes history and biomic occupancy patterns

Our results proposed generalist biome occupancy in basal crown Galliformes with ancestral presence in evergreen tropical rainforest, tropical deciduous forest, savanna and temperate evergreen forest (Fig.1). This broad ancestral occupancy is consistent with the early evolution of Galliformes. The first unambiguous presence of Galliformes in the fossil record is Paleocene (Mayr 2009; Hwang et al. 2010). Paleocene and Eocene species represent *stemgroup* families, which reached great diversity in the Northern Hemisphere (Mayr 2009). The earliest stem-family Gallinuloididae, would have spread by moist forest ecosystems in Europe and North America during the early and middle Eocene (Mayr and Weidig 2004), periods with warm climate (Zachos et al. 2001; Fine and Ree 2006; Zachos et al. 2008). Anatomical traits relative to the furcula and *sternal carina* in Gallinuloididae indicate the possible presence of an undeveloped crop respect to derivate lineages. In addition, none of known fossil specimens preserved gastroliths for mechanical digestion of hard plant matter such as seeds (Mayr and Weidig 2004; Mayr 2009). These evidences suggest that dietary requirements in early galliforms consisted of fruit and other soft vegetable material, which is consistent with occupation of the warm and wet tropical forested biomes predominant during the Eocene. Likewise, our findings agree with the broad biome distribution and dietary innovations inferred for the ancestral stem lineage Quercymegapodidae, which is phylogenetically closest to the crown Galliformes. This lineage inhabited the late Eocene forest environments in Europe and South America (Mourer-Chauviré 1992; Mayr 2009) and showed the first evidence of gastroliths in landfowls (Mayr 2009). This adaptation implied a high digestive capacity to process different sources of plant matter suggesting a great versatility to exploit novel feeding resources provided by the colonization of emerging semiarid and temperate biomes during the late Eocene and early Oligocene (Retallack 1992; Jacobs 2004; Jaramillo et al. 2006; Lindow and Dyke 2006; Werneck et al. 2011; Jaramillo and Cárdenas 2013). Global temperature decrease and the aridification towards the Eocene-Oligocene boundary (Zachos et al. 2001) are possibly related to the broad biome occupancy of crown-Galliformes ancestors. This would be a response to the fragmentation of evergreen tropical rainforests with expansion of tropical deciduous woodlands and savannas vegetation derived from a

strong seasonality in precipitation (Woodward et al. 2004). Our results showed a subsequent process of specialisation in tropical deciduous woodland and the withdrawal of the evergreen tropical rainforest and temperate evergreen forest in several Oligocene lineages (Fig.1).

Along the Oligocene and the Miocene, the tropical deciduous woodland biome would have played an important role in the diversification of the main clades of Galliformes. During this period the evolution of ancestral occupation for main clades conserved the presence in this biome. The digestive versatility in relation to novel plant sources during dry periods probably was a key factor to explain the observed trends in specialization and biome conservatism in the tropical deciduous woodlands. Likewise, this trait would have allowed the colonization of other emerging seasonal biomes with plants adapted to arid and dry conditions such as savanna or steppe (Fig.1). In general, the tropical deciduous woodland probably was conserved because their niches evolved in close relationship with seasonal aridity in tropical and subtropical latitudes (Pennington et al. 2004b). According to paleoclimatic evidence of plant and pollen fossils, dry forested and semi-open grassland ecosystems presented a continuous expansion along the Miocene to present times (Burnham 1995; Wang et al. 2014; Lavin et al. 2005).

Our results showed that Megapodidae extended during the middle and late Miocene across the tropical deciduous woodland biome arising in Australia and adjacent islands (Pennington et al. 2004a; Martin 2006; Byrne et al. 2008) (Fig.1). During the Pliocene some lineages (i.e *Megapodius*) colonized the evergreen tropical rainforest environments in diverse periods (Fig.1). Due to the vicariance processes in the last 3 million years associated to geographic isolation of rainforest fragments in relation to cooling periods during glacial periods and sea level elevations by interglacial periods many species diversified in this biome (Williams and Pearson 1997; Voris 2000; Meijaard 2003; Filardi and Moyle 2005; Woodruff 2010; Harris et al. 2014).

Cracidae subfamilies diverged during the late Miocene towards two climatic niches (Figures 1). According to fossil evidence, ancestral cracids such as *Ortalis* inhabited the Miocene of North America (Wetmore 1930), which presented dry open and semi-open environments such as tropical deciduous woodland (Wang et al. 1994; Pound et al. 2012). Our results suggest a divergence process in biome

occupancy during the late Miocene, which would be supported by the closure of the Panamanian land bridge during the Miocene (Hoorn and Flantua 2015; Montes et al. 2015) allowing the entering in South American environments (Weir et al. 2009). The initial colonization of temperate evergreen forest probably was related to the intense period of mountain building in Panama landbridge, previous to the dispersal into South America (Hoorn and Flantua 2015). During the orogeny, when a critical elevation is reached (1500 - 2000 m), the temperature drop probably altered the precipitations and increased the humidity, which established the new montane forest (temperate evergreen forest biome analogous) of the highlands of Central and South America (Holdridge 1967; Renjifo et al. 1997; Hoorn et al. 2010). The emerging of montane biome would allow the specialization of Penelopinae in new niches while another clade including the rest of subfamilies specialized in tropical deciduous woodland. Finally, our findings suggest several independent colonization events for the evergreen tropical rainforest during the Pleistocene. During the dry periods related with the glaciations, the isolation of rainforest fragments near areas in the periphery of Amazonia were separated by dry forest and savannas, along dry climatic periods (Haffer 2008). This scenario would allow the vicariance in the refugia according with the specialization processes of many taxa within this biome (Bennett et al. 2012; Jaramillo 2012). Likewise, the historical climatic dynamics of tropical evergreen rainforest in close association with deciduous woodland and temperate evergreen forest in mountains regions of tropical latitudes, allowed new colonization events between these biomes (Pennington et al. 2000; Hooghiemstra and Van der Hammen 2004; Haffer 2008). This is confirmed by our results as well as by other studies focussing on other rainforest taxa such as Cebidae monkeys (Alfaro et al. 2015), trumpeters (Ribas et al. 2011) and parrots (Ribas et al. 2009; Quintero et al. 2013).

Numididae apparently evolved under the influence of the African aridification of the late Neogene (Bobe 2006; Hernandez Fernandez et al. 2007; Senut et al. 2009). The observed specialization and biome conservatism of savannas during most of the evolutionary history of Numididae (Figures 1) is in concordance with the increase of open and arid habitats dominated by C4 grasslands in Africa since the late Miocene (Pickford 1992; Jacobs 2004; Beerling and Osborne 2006; Edwards et al. 2010). The seasonal climatic similarity between tropical deciduous woodland and savanna, probably allowed the adaptation of guinea fowl lineages to these conditions

(Davies 1982; Dean et al. 2009). Along Plio-Pleistocene glaciations, there was an intense aridification of Africa (de Menocal 2004; Sepulchre et al. 2006; Senut et al. 2009) and an important reduction of rainforest areas (Plana 2004) with a consequent increase of savannas (Jacobs 2004; Bouchenak-Khelladi and Hodkinson 2011). According to this, during the savannas driest periods, the arid conditions might promote diverse adaptations and nomadic habits (Tieleman et al. 2003), which facilitated dispersal events towards zones with water availability in ecotone areas of savanna with tropical deciduous woodlands and evergreen tropical rainforests (Lloyd 1999; Dean et al. 2009). These habits may have favoured the colonization of tropical evergreen rainforest in equatorial Africa and tropical deciduous woodlands biomes conserving the ancestral savanna occupation.

The family Odontophoridae diverged in two basal lineages. First, the African Ptilopachinae (Cohen et al. 2012) showed a biome occupancy associated with the savanna and tropical deciduous woodland during the late Miocene, in a aridification-driven pattern that resembles that of Numididae (Jacobs 2004; Senut et al. 2009). The American Odontophorinae presented two main tendencies of biome occupancy in Nearctic and Neotropics. North American ancestors of lineages as *Colinus* and *Callipepla* inhabited tropical deciduous forest and were able to colonized during the Plio-Pleistocene other dry and relatively open environments such as savannas, deserts and sclerophyllous woodland-shrublands. This process would be associated to geological and climatic events in relation to the Sierra Madre plateau uplift between the late Miocene and Pliocene, sea transgressions in the California Peninsula during different moments since the Miocene, and Pleistocene glacial-interglacial alternance (Zink and Blackwell 1998; Riddle and Hafner 2006). Meanwhile, for Neotropics, our results suggest process of colonization of temperate evergreen forest between late Miocene and early Pliocene for the clade that includes *Odontophorus* species (Fig.1). This is consistent with the origin of montane environments in Central and South America during the uplift of the Panamanian landbridge and the subsequent phases of elevation in the northern Andes (Hoorn et al. 2010; Montes et al. 2012; Montes et al. 2015), which propitiated vicariance similarly to what has been found in other bird groups (Fjeldsa° 1992; Quintero et al. 2013; Sweet and Johnson 2014). In general, these results show broad consistency with the patterns previously explained for Penelopinae, which suggests a common historical context for parallel evolution of Neotropical montane groups in relation to the biomes dynamics.

Whereas Numididae specialized in savanna environments, Phasinidae ancestors conserved the ancestral occupation associated with tropical deciduous woodland environments reaching a prominent diversification during the middle and late Miocene within a context of high biome conservatism (Fig.1). The fossil record suggest a broad distribution of Phasianidae in Eurasia around the late Oligocene to middle Miocene (Li et al. 1983; Rich et al. 1986; Sánchez Marco 1999; Mayr 2009; Zelenkov 2009), These basal phasianids were associated with dry and seasonal forest environments, which emerged in many regions in relation to the increasing of dryer and cooler conditions that fragmented originally moist forest areas (Zachos et al. 2001; Guo et al. 2008; Bozukov et al. 2009; Ivanov et al. 2011).

Along the diversification of Phasianidae (Fig.1) our results suggest influence of biotic interchange events between Europe, Asia, and Africa in the occupancy of different biomes. During the early Miocene, Africa-Arabia collided with Eurasia. This event altered the atmospheric circulation and at the same time the rifting and local uplift blocked the flow of humidity across Africa (Pickford 1992; Bobe 2006; Sepulchre et al. 2006; Senut et al. 2009). The widespread evergreen tropical rainforest was fragmented and replaced by tropical deciduous woodland with many seasonal forest environments (Jacobs 2004; Plana 2004; Bobe 2006). Our findings suggest that *Xenoperdix* clade diverged from *Arborophila* clade invading Africa during the early Miocene probably through the *Gomphotherium* land bridge around 18 Ma (van der Made 1999; Koufos et al. 2005). The interchange between Eurasia and Africa for Galliformes was possible during many periods along the Miocene, while the seasonal conditions of tropical deciduous woodland and savanna existed in Arabia, before the Plio-Pleistocene desertification and isolation by the Red Sea (Dinesen et al. 1994; Pound et al. 2012). Precisely, clades such as *Pternistis* (Coturnicini) and *Francolinus* and allies (Gallini) represent a parallel colonization of African tropical deciduous woodlands during Late Miocene in concordance with the *Hipparion* event (van der Made 1999). These lineages preserved their ancestral biome and reached a high ecological diversification, colonizing possible emerging dry woodland in Africa caused by rainforest contraction (Crowe et al. 1992; Pickford 1992; Jacobs 2004; Pound et al. 2012).

Considering Coturnicini, clades such as *Coturnix* and *Synoicus* with origin in tropical deciduous woodland showed a generalist biome occupation possibly related

with the development of migration behaviour and physiological versatility, which allowed them to achieve a high dispersal capacity and colonized a broad variety of biomes (Rolland et al. 2014; Pelegrin et al. 2015) reaching a wide geographical distribution in Eurasia and even Australia during the Pliocene and Pleistocene. The Coturnicini temperate clades showed two main colonization events from their ancestral biome: the steppes colonization by *Tetraogallus* and the occupation of broadleaf deciduous forests by *Alectoris*. In the case of *Tetraogallus*, the evolution of snowcock in central Asia is consistent with cooling process during the late Miocene and the orogeny processes triggered by the Tibetan Plateau and Caucasus uplift (van Dam 2006; An et al. 2015). Progressive vegetation changes and arising of cold and open environments in central Asia drove the colonization and subsequent specialization in emerging steppes; the glacial interglacial alternance caused the fragmentation of snowcock steppe habitats, resulting in the isolation of populations in mountainous systems and subsequent speciation events during the Pleistocene (Yang et al. 2009; Qu et al. 2010; An et al. 2015). *Alectoris* ancestors during the late Miocene colonized the broadleaf deciduous forest from tropical deciduous woodland, which expanded along central and east Europe regions during middle and late Miocene (Pound et al. 2012). Subsequently, vicariance between Southern Europe and Northern Africa was possible under the influence of the Messinian event and the Zanclean flood (Garcia-Castellanos et al. 2009). The Eurasian populations adapted initially to tropical deciduous woodlands, colonized the broadleaf deciduous forests, which were present during the early Pliocene in continental Europe and the Mediterranean basin (Hernandez Fernandez et al. 2007). The continuing global cooling process caused the specialization in broadleaf deciduous forests. Our results suggest diversification by colonization of sclerophyllous shrubland-woodland and steppe environments from broadleaf deciduous forest during the Pleistocene, which is consistent with the origin of sclerophyllous environments (Hernandez Fernandez et al. 2007; Buerki et al. 2012) and the refugia model for Mediterranean fauna (Hewitt 2003; Sánchez Marco 2004; Ferrero et al. 2011; Abellán and Svenning 2014).

The Eurasian most specious phasianid lineages present two main tendencies in their biome occupancy patterns. The results suggest a divergence process c.a 15 Ma associated with the colonization of broadleaf forest by the clade Lophophorini-Tetraonini-Phasianini while the lineage Polyplectronini-Pavonini-Gallini conserved the ancestral occupation in the tropical deciduous woodland. This suggests an initial

dispersal scenario towards temperate latitudes following a reinforced latitudinal temperature gradient of the Mid-Miocene Climatic Optimum (Zachos et al. 2001). Around this time, the biomes configuration was constituted by boreal coniferous forest at the high northern latitudes, extensive warm-temperate mixed forest in the middle and subtropical latitudes and finally, tropical forest biomes in tropical and equatorial latitudes (Pound et al. 2012). The Himalayan and Tibetan plateau orogeny constituted a geographical barrier that possibly had a significant influence on the separation and later diversification of both lineages. The Tibet system experimented during the early Miocene (20 Ma) a gradual elevation increase and would reached its present configuration around 8 Ma (Miao et al. 2012; Lei et al. 2014). However there is a broad debate that propose a more recently uplift process (Lei et al. 2014). The recent geological history of Himalayas and Tibetan Plateau includes different events (Spicer et al. 2003; Yang et al. 2009; Lei et al. 2014) that caused important climatic and ecological changes (Guo et al. 2008; Liu et al. 2009; Yao et al. 2011; Miao et al. 2012; Pound et al. 2012), including an intensification of cooling and aridification in central Asia and the increase of the monsoon regime in the southern and eastern Asia (Shi et al. 1999; Zheng et al. 2004; Liu et al. 2009). Every uplift event produced a fragmentation of biomes by modification of the local precipitation patterns, creating novel scenarios for vicariance of the tropical lineages Polyplectronini, Pavonini and Gallini in the tropical deciduous woodlands of India and Indochina (Zhisheng et al. 2001; Zheng et al. 2004; Yao et al. 2011; Miao et al. 2012).

The ancestral biome occupancy in broadleaf deciduous forest of Lophophorini and its geographical distribution suggest an initial process of colonization of arising biomes with the Tibetan system formation. During the late Miocene and early Pliocene there was a colonization of emerging mountain biomes such as boreal coniferous forests and steppes during the progressive uplift, the global cooling and aridification (Wen and Liu 2010). During the middle Miocene Tetraonini branched off from Phasianini conserving the occupation of broadleaf deciduous forest biome. This biome conservatism and the geographic distribution of the implied clades suggest a second event of isolation under the influence of the Tibetan Plateau uplift. According to this, the Tetraonini ancestors would colonize the northern areas of broadleaf deciduous forest at high latitudes. The northwards expansion of Tetraonini can explain the divergence process that caused the separation of turkeys lineage c.a 11

Ma, possibly caused by the colonization of North America through the '*Hipparion* landbridge' (van der Made 1999). Around the late Miocene, Tetraonini as well as Lophophorini colonized the taiga biome favoured by global cooling and the extension of this biome towards southern latitudes, reducing the predominance of temperate environments (Pound et al. 2011; Miao et al. 2012). The grouses diversified within the boreal coniferous forest biome possibly through the development of new physiological adaptations to the cold conditions of this environment (Andreev 1988). Likewise, the biome occupation associated with cold environments would have allowed their spread throughout Europe and the colonization of North America via the Bering Landbridge in diverse episodes during the so called 'Elephant-*Equus* event' (Martínez-Navarro 2010) and Pleistocene glaciations (Ogasawara 1998; Marincovich and Gladenkov 2001). The adaptations to colder conditions would have acted like as constraint in the adaptation to other climates regime, allowing only to colonize emerging cold biomes such as steppes and the arctic tundra during the Plio-Pleistocene (Weir and Schluter 2004).

On the other hand, the results for Phasianini showed the conservatism of broadleaf deciduous forest occupancy during its early cladogenesis. These findings suggest the colonization and subsequent vicariance in temperate biomes east of the Tibetan plateau, which might have relation with the late Miocene and Pliocene tectonic processes in Tianshui-Huicheng region that caused the formation of barriers and valley systems (Miao et al. 2012). This scenario promoted the emergency of diverse vicariance events and new biomes in highlands and lowlands of subtropical latitudes from China as well as influenced the relocation of atmospheric water from monsoon in the Eastern Asia (Shi et al. 1999; Wang et al. 2011; Miao et al. 2012) changing the regional biomes configuration. This enabled speciation in temperate evergreen forest and broadleaf deciduous forest at lowland lineages such as *Syrmaticus* or in mountain environments for *Perdix* and *Crossoptilon* lineages (Lei et al. 2014). During the late Miocene, the *Lophura* lineage spread towards the tropical deciduous woodland, which expanded across important areas in the South East of Asia due to the monsoon climate regime (Zhisheng et al. 2001; Zheng et al. 2004). These novel conditions promoted the emergency of new niches and the subsequent colonization of tropical deciduous woodland in tropical latitudes by lineages coming from broadleaf deciduous forest in subtropical ones. Our results for Phasianini are broadly consistent with the recent geographical distribution patterns and the high level of endemism

reported for Chinese mountain areas and forest environments in the Asian South East (Lu et al. 1997; Randi et al. 2001; Huang et al. 2009; Lei et al. 2014).

4.5.2. Falconiformes history and biomic occupancy patterns

The reconstruction of ancestral biome occupancy in Falconiformes (Fig.4) during the Oligocene reveals an origin associated with tropical biomes: evergreen tropical rainforest, tropical deciduous woodland and savanna. These findings are consistent with Falconiformes originating in the Neotropics. This origin is supported by the presence and diversification of endemic basal lineages (Herpetotherinae and Polyborini) (Fuchs et al. 2011; Fuchs et al. 2012). Also, the oldest record for crown clade Falconidae (*Pedohierax* and *Thegornis*) is Neotropical (Tambussi et al. 1995; Noriega et al. 2011; Tambussi and Degrange 2013). Finally, under a phylogenetic point of view, Falconiformes is part of the Australaves clade (Falconiformes, Cariamiformes, Psittaciformes and Passeriformes), which presumably evolved in South America-Antarctica-Australia-Zealand (Ericson 2012; Jarvis et al. 2014) (see also Chapter 3). At the Eocene-Oligocene boundary the opening of the Drake passage and the subsequent glaciation in Antarctica caused cooling and drying trend (Francis et al. 2008; Zachos et al. 2008), which triggered an important reduction of evergreen tropical rainforest in South America (Fine and Ree 2006; Jaramillo et al. 2006), and the expansion of drier environments such as tropical deciduous woodland and the initial emerging of savannas (Ortiz-Jaureguizar and Cladera 2006; Edwards et al. 2010).

During the Oligocene, the divergence between Herpetotherinae and Falconinae probably was influenced by diverse processes such as the establishment of an ecological gradient triggered by the Oligocene cooling trend, the beginning of Andean orogeny and the Oligocene-Miocene sea transgression (Lundberg et al. 1998; Ortiz-Jaureguizar and Cladera 2006; Tambussi and Degrange 2013). These processes would have promoted vicariance between both lineages. Herpetotherinae expanded towards northern and western areas following the Andean influence zone. Meanwhile, Falconinae ancestors would have spread eastwards to the Brazilian area.

The Herpetotherinae ancestors during the early Miocene colonized the temperate evergreen forest (Fig.4), this event was caused possibly by modification in the Andean arc (Uliana and Biddle 1988; Ortiz-Jaureguizar and Cladera 2006; Hoorn et al. 2010), which originated new montane environments with temperate conditions

(Hoorn et al. 2010). During the middle Miocene *Herpetotheres* separated from *Micrastur*, probably *Herpetotheres* dietary habits such as exclusive snake hunter allow them occupy a specific ecological niche but achieve a broad geographical distribution (Ferguson-Lees and Christie 2001) in relation to the wide distribution and diversification that snakes species present in diverse habitats in the Neotropics during the Neogene (Cadle and Greene 1993; Daza et al. 2010; Pyron and Burbrink 2012). *Micrastur* showed a diversification pattern associated specially with tropical evergreen rainforest and tropical deciduous woodland. These results suggest that *Micrastur* species possibly were affected for diverse processes that fragmented these biomes since the middle Miocene and the Pliocene. During this time span, the consolidation of Pebas lake system (c.a 17-9 M.a) (Wesselingh and Salo 2006), the mountain building in the central and northern Andes (c.a 12 M.a) and the continuous uplift of Northern Andes that defined "Pan-Amazonia" region (c.a 10 M.a) (Lundberg et al. 1998; Campbell et al. 2006; Hoorn et al. 2010) were processes that would have promoted the initial divergence for the *Micrastur* lineages in two main clades (Fig.4). The broad geographic distribution reached by *M. semitorquatus* or *M. ruficollis* suggest that, despite their forested habitat preferences, these raptor-birds could develop a high dispersal capacity (Ferguson-Lees and Christie 2001), which might have allowed the expansion towards similar biomes through lowlands and Andean slopes in northern South America (Hooghiemstra and Van der Hammen 2004; Jaramillo and Cárdenas 2013).

The separation of *S. circumcincta* respect to the caracaras lineage (Fig.4) was triggered probably in relation to biome specialisation in the arising open and dry savannas in southern South America during the early Miocene (Pennington et al. 2004b; Ortiz-Jaureguizar and Cladera 2006). Conversely, the caracaras lineage conserved the ancestral generalist biome occupation, which allow them to spread towards biomes that were originated in different zones of Southern South America, especially in subtropical latitudes during Miocene cooling periods (Pound et al. 2012; Le Roux 2012). A body-size increase in the caracara lineage respect to *Spiziapteyx* may have caused changes in the dietary spectrum related to their trend towards ecological generalization; the caracaras developed a generalist/scavenging-like behaviour (Ferguson-Lees and Christie 2001) that allowed them gradually to colonise many biomes during the Plio-Pleistocene. This pattern is consistent with the apparition and radiation of other biome generalist birds with scavenging habits in

South America such as the New World vultures (Pelegrin 2009; Fuchs et al. 2012; Tambussi and Degrange 2013).

During the late Miocene the ancestors of the *Ibycter-Phalcoboenus* clade branched off from the *Caracara* lineage (Fig.4) possibly due to Miocene and Pliocene biome shifts that increased the dominance of tropical deciduous woodland and savannas in South America. The biome shifts and associated fragmentation probably generated process of vicariance in zones such as the Cerrado (tropical deciduous woodland) or the Caatinga (savanna) (Pennington et al. 2004b; Werneck 2011). The ecological relationship between these areas and the close evergreen tropical rainforest would lead to lineages such as *Ibycter*, *Daptrius* or *Milvago* to invade this environment during the rainforest contractions triggered by the Pleistocene glaciations. Meanwhile, *Phalcoboenus* lineage colonized during Pleistocene colder and more seasonal biomes. This lineage probably spread along the Andes mountain system conserving the presence in highland steppes and diverging by isolation of populations due to the glacial-interglacial ciclycity (Hooghiemstra 1989; Hooghiemstra et al. 1995; Ortiz-Jaureguizar and Cladera 2006).

Our findings presented a divergence between Polyborini and Falconini conserving the ancestral biome occupancy, which suggest a dispersal scenario out of South America colonizing the Old World during the late Oligocene. According to paleogeographical evidence, South America and Africa were closer during the late Oligocene (around 1800 km respect to 2900 km in modern times) (Scotese 2001). In addition, the basal position of *Polihierax* in Falconini clade and its anatomical and ecological features may suggest that ancestral Falconinae were small size species with pointed wings for fast undulating fight and dietary habits mainly associated with little animals such as insects or lizards (Del Hoyo et al. 1994; Kemp and Crowe 1994; Ferguson-Lees and Christie 2001). Considering this context, the hypothetical ancestral development of high flight capacity, the relatively proximity between South America and Africa, and the apparently low water dependence reported for the pygmy falcons (Anderson et al. 1999) probably were some important factors that eased the transoceanic dispersal (De Queiroz 2005; Gillespie et al. 2011). A similar scenario, but in other direction, has been proposed for bird taxa apparently exclusive from the Neotropics such as the hoatzin (Mayr and De Pietri 2014) as well as for mammals such as New World monkeys and rodents (Poux et al. 2006). The long-

distance fly capacity legacy would have enabled *Microhierax* ancestors to expand into tropical deciduous woodland and evergreen tropical forest biomes in Indian subcontinent and southeast Asia by the "stepping stones" route formed in the Indian Ocean through Madagascar and Seychelles islands, which is proposed as an important bridge between Africa and India by studies on other taxa (Warren et al. 2010; Condamine et al. 2013).

Regarding the falcons lineage, their ancestor underwent a extinction of lineages in evergreen tropical forests and a subsequent radiation and ecological specialization during the middle and late Miocene associated with open habitats (Fuchs et al. 2015). In this context, the reconstructed scenario and the biome occupation tendencies are in concordance with the increase of open, dry and seasonal environments and shrinkage of rainforest (Jacobs 2004; Senut et al. 2009; Edwards et al. 2010). The phylogeny presents a divergence event between the *Falco* lineage and *Polihierax insignis* during the middle Miocene. The extant Indochinese presence of *P. insignis* may suggest a scenario where *Microhierax* ancestors and *P. insignis* dispersed from Africa and colonized Asia independently. This agree with previous notions of an Asian or African origin for *Falco* (Olson 1985; Becker 1987; Boev 2011; Fuchs et al. 2015). This process could have taken place through the stepping stones connection (Yoder and Nowak 2006; Warren et al. 2010) or across the land bridge that enabled the *Conohyus/Pliopithecus* event, with many Eurasian taxa entering in Africa around 14 Ma (van der Made 1999). The presence of tropical deciduous woodlands and savannas in the Middle East during this period (Edwards et al. 2010; Pound et al. 2012) might have propitiated this expansion towards Asia.

Middle Miocene *Falco* ancestors were associated with tropical deciduous woodlands and savannas and presented a subsequent radiation in the late Miocene. The fossil record evidences a broad distribution of *Falco* in Eurasia since the middle and late Miocene (Mlíkovský 1996, 2002; Boev 2011; Li et al. 2014) and crossed to North America through Beringia (Becker 1987). Both continents, especially the eastern Mediterranean, western-central Asia and the Great Plains underwent a profound ecological transformation with the expansion of C4 grasses in open, dry and seasonal environments, associated to climate changes and variations in the CO_2 levels (Cerling et al. 1993; Wang et al. 1994; Latorre et al. 1997; Edwards et al. 2010; Strömberg and McInerney 2011; Fraser and Theodor 2013). There are evidences of

Falco bulgaricus, from late Miocene Bulgaria associated to typical tropical deciduous woodland and savanna megafauna (Boev 2011). *Falco hezhengensis*, from late Miocene central Asia (China), included jerboa (Dipodidae) in its diet, indicating their presence in transitional savanna-steppe grasslands (Li et al. 2014).

Our results suggest that *Falco* diversification during the late Miocene into two main lineages: the *F.zoniventris*-group and the *F. sparverius*-group was in close association with open, dry and seasonal biomes such tropical deciduous woodland and savannas. During this period, the spread of open environments (Cerling et al. 1993) coincided also with the diversification of many rodents groups (Smith and Patton 1999; Galewski et al. 2006; Lecompte et al. 2008; Fabre et al. 2012), an important feeding source of falcons. Considering the *Falco zoniventris*-group, the close association with the savanna biome is consistent with the African scenario proposed for the evolution of this clade (Groombridge et al. 2002). Also, it would have been concomitant with an important increase of aridity in Africa during the Plio-Pleistocene, which culminated with the development of the Sahara desert (Hernandez Fernandez et al. 2007; Senut et al. 2009).

The phylogeny and the geographic distribution for the *Falco sparverius*-group suggest a biogeographic scenario with multiple biome colonization events between Eurasia and North America, and subsequent peripheral dispersal events towards Africa, Australia and South America. These interchanges are consistent with sea level fluctuations during the glacial periods and the establishment of land bridges such as Beringia, or biotic interchange events as the Elephant-*Equus* or *Pachycrocuta* (Sanmartín et al. 2001; Nores 2004; Martínez-Navarro 2010; DiNezio and Tierney 2013).

Overall, the diversification of kestrels and falcons in relation to the obtained patterns of biomes colonization may suggest that the initial development of a high flight capacity associated with seasonally environments by Falconini ancestors might had an important role as exaptation (Gould and Vrba 1982) for the ulterior independent development of a true migration behaviour in many falcon lineages (Rolland et al. 2014; Fuchs et al. 2015). This feature explains the dispersal capacity of this clade and the relatively frequent colonization of adverse environments such as deserts, steppes or tundras (Pelegrin et al. 2015) where these lineages show a high level of conservatism. The ancestral development of a wide spectrum of feeding and

physiological adaptations, such as tolerance to high body temperatures and the low water dependency related to their carnivorous habits (Bartholomew and Cade 1957; Masman et al. 1989) might have evolved in savanna-like conditions and enabled the adaptation to the dryer climatic environments of the recently appeared deserts and steppes consolidated in the Northern Hemisphere during the Pleistocene (Fine and Ree 2006). According to our findings these relatively recent biomes and others such as sclerophyllous woodland-shrubland and the expanding taiga were colonized by relatively young lineages, which is consistent with the speciation patterns observed for many Holarctic vertebrate clades during the Pleistocene ice-ages (Hewitt 2000; Weir and Schluter 2004).

4.5.3. Patterns of biome colonization in Galliformes and Falconiformes

Along the time the results for Galliformes suggest different phases of biome colonization (Fig.4), during the early Oligocene the tropical deciduous woodland and the temperate evergreen forest presented an outstanding growing. Probably these results are related with the global cooling trend (Zachos et al. 2001) that affected the extension of tropical evergreen forest zones causing its fragmentation and contraction. These processes would have promoted the colonization of emerging habitats in drier tropical deciduous woodlands and temperate evergreen forests in northern latitudes (Collinson and Hooker 2003). Around the Oligocene-Miocene boundary, the savanna registered an increase of colonizations reaching a maximum value during the early Miocene, which is consistent with the early replacement of grassland biomes that began to supplant forestlands (Jacobs 2004; Edwards et al. 2010). Likewise, the savannas experimented a second colonization increase during late Miocene and Pliocene, in line with the worldwide expansion of C4 grasslands, event that possibly generated new savannas environments (Cerling et al. 1993; Bouchenak-Khelladi and Hodkinson 2011). During the early Miocene the broadleaf deciduous forest biome presented an increase of colonizations. This process might be related to the ecological gradient established by the initial Himalayan uplift (Shi et al. 1999; Miao et al. 2012; Guo et al. 2008), which affected significantly the evolution of Phasianidae lineages in Asia. There was a marked growth in the colonization rates for the majority of biomes in the middle and late Miocene times. After the Mid-Miocene Climate Optimum, the global decreasing in temperatures generated tendencies towards cooling and aridification that intensified the emergence of

seasonal biomes. Likewise, biomes such as the evergreen tropical rainforest presented a significant reduction and fragmentation. According to this, our findings showed an important increase in colonization rates for this biome. The patterns observed for evergreen tropical rainforest suggest that contractions probably promoted the colonization events of many tropical lineages by dispersal events from proximal biomes toward diverse rainforest blocks consolidating the early endemism areas (Cracraft 1985) during the middle and late Miocene. Thus, Plio-Pleistocene rainforests would have subsequently acted such as refugia for many lineages during cooler periods. This would have promoted vicariance according to our findings and other studies based on rainforest faunas (Haffer 2008; Bennett et al. 2012). Since the late Miocene the seasonal biomes presented a progressive pattern of expansion, until their consolidation in the Pleistocene. Probably expansion in biomes such as deserts (Senut et al. 2009), steppes (Miao et al. 2012; Humphreys and Linder 2013), taigas (Pound et al. 2011) and sclerophyllous woodland-shrublands (Hernandez Fernandez et al. 2007) might facilitate the novel emergency of ecological niches, which made possible the increasing observed in the colonization patterns for these environments until the Plio-Pleistocene. Likewise, with the glacial-interglacial alternancy, whereas a few lineages adapted to tundra biomes, many of these biomes were important refugia areas of endemism for many lineages with climatic constraints (Hewitt 2000; Weir and Schluter 2004; Abellán and Svenning 2014; An et al. 2015).

Our findings for Falconiformes (Fig.5) suggest that during the Oligocene only the temperate evergreen forest was colonized, this biome would appeared during the initial uplift phases of Andes uplift (Hoorn et al. 2010). The observed pattern probably has relation with the basal evolution of Falconiformes restricted to South America where they probably occupied a broad spectrum of tropical biomes. Interestingly, conserving the tropical affinities along their early diversification. During the middle Miocene the falcons presented a significant increase of colonization processes in evergreen tropical forest and deciduous woodland biomes as well as temperate evergreen forest in the mountains (Hoorn et al. 2010). During this period, the intense uplift process of Andes caused the continuous fragmentation in the tropical forest biomes (Wesselingh and Salo 2006) and the arising of new ecological niches and vicariance scenarios in Neotropic lowlands (Valderrama et al. 2014).

The colonization of more arid biomes took place during the late Miocene. This timing fit the colonization reported for Galliformes and is probably connected to the global cooling that followed the Mid-Miocene Climate Optimum (Zachos et al. 2001; van Dam 2006; Liu et al. 2009; Senut et al. 2009). Moreover, the diversification of falconids out of South America probably increased the possibility of colonizing new environments. According to this, the results showed an increase during the late Miocene in colonization for semi-open biomes such as tropical deciduous woodlands and sclerophyllous woodland-shrubland as well as open biomes such as deserts, savannas and steppes. All these findings are consistent with fossil evidences (Boev 2011; Li et al. 2014). During this period, these seasonal biomes expanded their distribution towards high latitudes and open environments acquired an especial ecological relevance (Bredenkamp et al. 2002; Edwards et al. 2010; Cerling et al. 1993). Likewise, during the late Miocene and Pliocene, the falconids also showed an increase of colonizations of temperate and high latitudes biomes such as broadleaf deciduous forest, boreal coniferous forest and tundra. These patterns support the previous development of different physiological traits (Klaassen 1996) and a high dispersal flight (Thorup 2006), probably linked to the evolution of migration, which made possible the dispersal into diverse environments (Rolland et al. 2014; Pelegrin et al. 2015). These factors could explain the observed similarity in the colonization patterns for diverse biomes at the same time and the diverse trends towards a significant presence of basal lineages in warm tropical biomes while the subtropical, temperate latitudes and cool or dry biomes in tropical ones were colonized by more derived lineages in subsequent times. These findings are broadly consistent with analyses of the relationship between niche conservatism and latitudinal diversity gradient in birds (Hawkins et al. 2006).

4.5.4. Trends in phylogenetic biome conservatism

The results obtained for the biome colonization patterns in Galliformes and Falconiformes (Figures 3, 6) revealed high levels of phylogenetic conservatism of biome (%BC) for landfowls and falcons. Biome occupancy was conserved along the phylogeny of Galliformes in 475 of 767 (61.92%) transition events while the colonizations were represented by 292 events (38.08%) (Table 2, Fig.3). For each biome the findings support BC values higher than 50%, except the savanna and sclerophyllous woodland-shrubland. Interestingly, biomes in the extreme of climatic

gradient consistently presented BC values above 75%: evergreen tropical rainforest (82.93%), steppe (83.78%) and tundra (100%). Meanwhile, Falconiformes also presented a high biome conservatism values with a similar proportion respect to Galliformes. The BC for Falconiformes was represented in 273 of 436 (62.61%) possible biome transitions while resting 37.39% are represented by 163 new biome colonizations (Table 3, Fig.6). Likewise, highest score values were registered for evergreen tropical rainforest (82.5%), steppe (77.8%), taiga (93.8%), and tundra (87.5%). In a broad view, despite their more generalist biome occupancy, the biome conservatism is strong in both Falconiformes and Galliformes. These similarities suggest common triggering processes such as abiotic changes. Such events would have mainly affected extreme biomes with the relative recent colonization of emerging steppes, taigas and tundras. The development of physiological adaptations to cold environments (McNab 2009) probably constitutes like constraints for subsequent colonizations (Hawkins et al. 2007). Likewise, the historical high resources availability and heterogeneity of habitats in tropical rainforest biome may constitute important factors promoting biome conservatism (Hawkins et al. 2003; Wiens 2004; Peterson and Nyari 2008) resulting in the existence of rainforest lineages since the Eocene and Oligocene.

Taken together, our findings depict both the tropical deciduous forests and the savannas as significant evolutionary arenas for both bird groups (Figures 3, 6). The significant biome colonization rates related to these biomes reveal their importance acting as possible species cradle and corridor. Due to their seasonal and thermic intermediate conditions (Pennington et al. 2006), these biomes might presented a broad spectrum of environmental variations, thus the species adaptation to seasonal and dry conditions of these biomes would have promoted the development of a broad physiological spectrum to cope such diverse environmental variations. This trend would have consolidated these biomes as species cradle. In this way, the wide adaptive spectrum allows the gradual colonization and subsequent specialization to the climatic condition of extreme biomes such as desert (Guerrero et al. 2013; Jara-Arancio et al. 2014). Under this context, bird evolutionary success might have resulted not by continuous adaptation to new environments but from the development of a broad adaptive physiological spectrum by particular lineages in seasonal biomes that would allowed the expansion and dispersal capacity to colonize areas with similar climatic conditions during climatic and geologic changes. In

particular, our work emphasizes the evolutionary importance of the tropical deciduous woodland in bird evolution. Despite the strong phylogenetic conservatism of savanna-adapted lineages, this biome represents an important connector between tropical and temperate biomes consoling a source of species for other biomes.

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4.7. LITERATURE CITED

Abellán P, Svenning JC (2014) Refugia within refugia: Patterns in endemism and genetic divergence are linked to Late Quaternary climate stability in the Iberian Peninsula. *Biol J Linn Soc* 113 (1):13-28

Alfaro JWL, Boubli JP, Paim FP, Ribas CC, da Silva MNF, Messias MR, Röhe F, Mercês MP, Júnior JSS, Silva CR (2015) Biogeography of squirrel monkeys (genus *Saimiri*): South-central Amazon origin and rapid pan-Amazonian diversification of a lowland primate. *Mol Phylogenet Evol* 82:436-454

An B, Zhang L, Liu N, Wang Y (2015) Refugia Persistence of Qinghai-Tibetan Plateau by the Cold-Tolerant Bird *Tetraogallus tibetanus* (Galliformes: Phasianidae). *PloS ONE* 10 (3):e0121118

Anderson MD, Maritz AW, Oosthuysen E (1999) Raptors drowning in farm reservoirs in South Africa. *Ostrich* 70 (2):139-144

Andreev A (1988) Ecological energetics of Palaearctic Tetraonidae in relation to chemical composition and digestibility of their winter diets. *Can J Zool* 66 (6):1382-1388

Axelrod DI (1966) Origin of deciduous and evergreen habits in temperate forests. *Evolution*:1-15

Axelrod DI (1985) Rise of the grassland biome, central North America. *The Botanical Review* 51 (2):163-201

Bartholomew GA, Cade TJ (1957) The body temperature of the American Kestrel, *Falco sparverius*. The Wilson Bulletin:149-154

Batalha-Filho H, Pessoa RO, Fabre P-H, Fjeldså J, Irestedt M, Ericson PG, Silveira LF, Miyaki CY (2014) Phylogeny and historical biogeography of gnateaters (Passeriformes, Conopophagidae) in the South America forests. *Mol Phylogenet Evol* 79:422-432

Becker J (1987) Revision of "*Falco*" *ramenta* Wetmore and the Neogene evolution of the Falconidae. *The Auk* 104:270-276

Beerling DJ, Osborne CP (2006) The origin of the savanna biome. *Glob Change Biol* 12 (11):2023-2031

Bennett KD, Bhagwat S, Willis K (2012) Neotropical refugia. *The Holocene* 22 (11):1207-1214

Bobe R (2006) The evolution of arid ecosystems in eastern Africa. *J Arid Environ* 66 (3):564-584

Boev Z (2011) *Falco bulgaricus* sp. n.(Aves: Falconiformes) from the late Miocene of Hadzhidimovo (SW Bulgaria). *Acta Zool Bulg* 63:17-35

Bouchenak-Khelladi Y, Hodkinson T (2011) Savanna biome evolution, climate change and the ecological expansion of C4 grasses. In: Trevor R, Hodkinson et al. (eds) *Climate Change, Ecology and Systematics*. Systematics Association Special Volume Series. Cambridge: Cambridge University Press:156-175

Bozukov V, Utescher T, Ivanov D (2009) Late Eocene to early Miocene climate and vegetation of Bulgaria. *Rev Palaeobot Palynol* 153 (3):360-374

Bredenkamp G, Spada F, Kazmierczak E (2002) On the origin of northern and southern hemisphere grasslands. *Plant Ecol* 163 (2):209-229

Buckner JC, Alfaro JWL, Rylands AB, Alfaro ME (2015) Biogeography of the marmosets and tamarins (Callitrichidae). *Mol Phylogenet Evol* 82:413-425

Buerki S, Jose S, Yadav SR, Goldblatt P, Manning JC, Forest F (2012) Contrasting biogeographic and diversification patterns in two Mediterranean-type ecosystems. *PLoS ONE* 7 (6):e39377-e39377

Burnham RJ (1995) A new species of winged fruit from the Miocene of Ecuador: *Tipuana ecuatoriana* (Leguminosae). *Am J Bot*:1599-1607

Byrne M, Yeates D, Joseph L, Bowler J, Cooper S, Donnellan S, Kearney M, Keogh J, Leijs R, Melville J, Murphy D, Porch N, Williams M, Wyrwoll K (2008) Birth of a biome: synthesizing environmental and molecular studies of the assembly and maintenance of the Australian arid zone biota. *Mol Ecol* 17:4398 - 4417

Cadle JE, Greene HW (1993) Phylogenetic patterns, biogeography, and the ecological structure of Neotropical snake assemblages. Species diversity in ecological communities: historical and geographical perspectives University of Chicago Press, Chicago:281-293

Campbell KE, Frailey CD, Romero-Pittman L (2006) The Pan-Amazonian Ucayali Peneplain, late Neogene sedimentation in Amazonia, and the birth of the modern Amazon River system. *Palaeogeogr Palaeoclimatol Palaeoecol* 239 (1):166-219

Cantalapiedra JL, Hernández Fernández M, Morales J (2011) Biomic specialization and speciation rates in ruminants (Cetartiodactyla, Mammalia): a test of the resourse-use hypothesis at global scale. *PLoS ONE* 6 (12):e28749.

Cantalapiedra JL, Hernández Fernández M, Morales J (2014) The biogeographic history of ruminant faunas determines the phylogenetic structure of their assemblages at different scales. *Ecography* 36:1-9

Cerling TE, Wang Y, Quade J (1993) Expansion of C4 ecosystems as an indicator of global ecological change in the late Miocene. *Nature* 361 (6410):344-345

Cohen C, Wakeling JL, Mandiwana-Neudani TG, Sande E, Dranzoa C, Crowe TM, Bowie RC (2012) Phylogenetic affinities of evolutionarily enigmatic African galliforms: the Stone Partridge *Ptilopachus petrosus* and Nahan's Francolin *Francolinus nahani*, and support for their sister relationship with New World quails. *Ibis* 154 (4):768-780

Collinson ME, Hooker JJ (2003) Paleogene vegetation of Eurasia: framework for mammalian faunas. In: Reumer JWF, Wessels W (eds) Distribution and migration of Tertiary mammals in Eurasia. *Deinsea* (10):41-83

Condamine FL, Sperling FAH, Kergoat GJ (2013) Global biogeographical pattern of swallowtail diversification demostrates alternative colonization routes in the Northern and Southern hemispheres. *J Biogeogr* 40:9-23

Cracraft J (1985) Historical Biogeography and Patterns of differentiation within the South American avifauna: Areas of Endemism. American Ornithologist Union, *Ornithology Monografts* 36:49-84

Crisp M (2006) Biome assembly: what we know and what we need to know. *J Biogeogr* 33:1332-1333

Crisp M, Arroyo MT, Cook LG, Gandolfo MA, Jordan GJ, McGlone MS, Weston P, Westoby M, Wilf P, Linder HP (2009) Phylogenetic biome conservatism on global scale. *Nature* 458:754-756

Crowe TM, Harley EH, Jakutowics MB, Komen J, Crowe AA (1992) Phylogenetic, taxonomic and biogeographical implications of genetic, morphological, and behavioral variation in francolins (Phasianidae: *Francolinus*). *The Auk* 109 (1):24-42

Davies S (1982) Behavioural adaptations of birds to environments where evaporation is high and water is in short supply. *Comp Biochem Physiol Part A: Physiology* 71 (4):557-566

Davies TJ, Buckley LB, Grenyer R, Gittleman JL (2011) The influence of past and present climate on the biogeography of modern mammal diversity. *Philos Trans R Soc B*: 366 (1577):2526-2535.

Davis CC, Webb CO, Wurdack KJ, Jaramillo CA, Donoghue MJ (2005) Explosive radiation of Malpighiales supports a mid-Cretaceous origin of modern tropical rain forests. *Am Nat* 165 (3):E36-E65

Daza JM, Castoe TA, Parkinson CL (2010) Using regional comparative phylogeographic data from snake lineages to infer historical processes in Middle America. *Ecography* 33 (2):343-354

de Medeiros MCM, Lohmann LG (2015) Phylogeny and biogeography of *Tynanthus* Miers (Bignonieae, Bignoniaceae). *Mol Phylogenet Evol* 85:32-40

deMenocal PB (2004) African climate change and faunal evolution during the Pliocene–Pleistocene. *Earth Planet Sci Lett* 220 (1-2):3-24

De Queiroz A (2005) The resurrection of oceanic dispersal in historical biogeography. *Trends Ecol Evol* 20:68-73

Dean WRJ, Barnard P, Anderson MD (2009) When to stay, when to go: trade-offs for southern African arid-zone birds in times of drought. *S Afr J Sci* 105 (1-2):24-28

Del Hoyo J, Collar NJ (2014) *HBW and BirdLife International Ilustrated Checklist of the Birds of the World*, vol I: Non-passerines. Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (1992) *Ostrich to Ducks. Handbook of the Birds of the World*, vol 1. Lynx Edicions, Barcelona

Del Hoyo J, Elliott A, Sargatal J (1994) *New World Vultures to Guineafowl. Handbook of the Birds of the World*, vol 2. Lynx Edicions, Barcelona

DeVore ML, Pigg KB (2013) Paleobotanical evidence for the origins of temperate hardwoods. *Int J Plant Sci* 174 (3):592-601

Dinesen L, Lehmberg T, Svendsen TO, Hansen LA, Fjeldså J (1994) A new genus and species of perdicine bird (Phasianidae, Perdicini) from Tanzania; a relict form with Indo-Malayan affinities. *Ibis* 136 (1):3-11

DiNezio PN, Tierney JE (2013) The effect of sea level on glacial Indo-Pacific climate. *Nat Geosci* 6 (6):485-491

Donoghue MJ (2008) A phylogenetic perspective on the distribution of plant diversity. *Proc Natl Acad Sci USA.*105:11549 - 11555

Donoghue MJ, Edwards EJ (2014) Biome shifts and niche evolution in plants. *Annu Rev Ecol Evol Syst* 45:547-572

Douglas ME, Douglas MR, Schuett W, Porras LW (2006) Evolution of rattlesnakes (Viperidae;*Crotalus*) in the warm deserts of western North America shaped by Neogene vicariance and Quaternary climate change. *Mol Ecol* 15:3353-3374

Edwards EJ, Osborne CP, Strömberg CA, Smith SA (2010) The origins of C4 grasslands: integrating evolutionary and ecosystem science. *Science* 328 (5978):587-591

Eo SH, Bininda-Emonds ORP, Carroll JP (2009) A phylogenetic supertree of the fowls (Galloanserae, Aves). *Zool Scr* 38 (5):465-481

Ericson PGP (2012) Evolution of terrestrial birds in three continents: Biogeography and parallel radiations. *J Biogeogr* 39:813-824

Fabre P-H, Hautier L, Dimitrov D, Douzery E (2012) A glimpse on the pattern of rodent diversification: a phylogenetic approach. *BMC Evol Biol* 12:88

Ferguson-Lees J, Christie DA (2001) *Raptors of the world*. Houghton Mifflin Harcourt

Ferrero M, Blanco-Aguiar JA, Lougheed SC, Sánchez-Barbudo I, De Nova PJG, Villafuerte R, Dávila JA (2011) Phylogeography and genetic structure of the red-legged partridge (*Alectoris rufa*): more evidence for refugia within the Iberian glacial refugium. *Mol Ecol* 20 (12):2628-2642

Filardi CE, Moyle RG (2005) Single origin of a Pan-Pacific bird group and upstream colonization of Australasia. *Nature* 438:216-219

Fine PVA, Ree RH (2006) Evidence for a time-integrated species-area effect on the latitudinal gradient in tree diversity. *Am Nat* 168 (6):796-804

Fjeldså J (1992) Biogeographic patterns and evolution of the avifauna of relict high-altitude woodlands of the Andes. *Steenstrupia* 18:9-62

Flower BP, Kennett JP (1994) The middle Miocene climatic transition: East Antarctic ice sheet development, deep ocean circulation and global carbon cycling. *Palaeogeogr Palaeoclimatol Palaeoecol* 108 (3):537-555

Francis J, Marenssi S, Levy R, Hambrey M, Thorn V, Mohr B, Brinkhuis H, Warnaar J, Zachos J, Bohaty S (2008) From greenhouse to icehouse: the Eocene/Oligocene in Antarctica. *Developments in Earth and Environmental Sciences* 8:309-368

Franzke A, Hurka H, Janssen D, Neuffer B, Friesen N, Markov M, Mummenhoff K (2004) Molecular signals for Late Tertiary/Early Quaternary range splits of an Eurasian steppe plant: *Clausia aprica* (Brassicaceae). *Mol Ecol* 13 (9):2789-2795

Fraser D, Theodor JM (2013) Ungulate diets reveal patterns of grassland evolution in North America. *Palaeogeogr Palaeoclimatol Palaeoecol* 369:409-421

Fuchs J, Chen S, Johnson JA, Mindell DP (2011) Pliocene diversification within the South American Forest falcons (Falconidae: *Micrastur*). *Mol Phylogenet Evol* 60:398-407

Fuchs J, Johnson JA, Mindell DP (2012) Molecular systematics of the caracaras and allies (Falconidae: Polyborinae) inferred from mitochondrial and nuclear sequence data. *Ibis* 154 (3):520-532

Fuchs J, Johnson JA, Mindell DP (2015) Rapid diversification of falcons (Aves: Falconidae) due to expansion of open habitats in the Late Miocene. *Mol Phylogenet Evol* 82:166-182

Galewski T, Tilak M-k, Sanchez S, Chevret P, Paradis E, Douzery EJP (2006) The evolutionary radiation of Arvicolinae rodents (voles and lemmings): relative contribution of nuclear and mitochondrial DNA phylogenies. *BMC Evol Biol* 6 (1):80

García-Castellanos D, Estrada F, Jiménez-Munt I, Gorini C, Fernández M, Vergés J, De Vicente R (2009) Catastrophic flood of the Mediterranean after the Messinian salinity crisis. *Nature* 462 (7274):778-781

Ghalambor CK, Huey RB, Martin PR, Tewksbury JJ, Wang G (2006) Are mountain passes higher in the tropics? Janzen's hypothesis revisited. *Integr Comp Biol* 46 (1):5-17

Giarla TC, Jansa SA (2014) The role of physical geography and habitat type in shaping the biogeographical history of a recent radiation of Neotropical marsupials (*Thylamys*: Didelphidae). *J Biogeogr* 41 (8):1547-1558

Gillespie R, Baldwin B, Waters J, Fraser C, Nikula R, Roderick G (2011) Long-distance dispersal: a framework for hypothesis testing. *Trends Ecol Evol* 27:47 - 56

Gould SJ, Vrba E (1982) Exaptation: A Missing Term in the Science of Form. *Paleobiology* 8 (1):4-15

Groombridge JJ, Jones CG, Bayes MK, van Zyl AJ, Carrillo J, Nichols RA, Bruford MW (2002) A molecular phylogeny of African kestrels with reference to divergence across the Indian Ocean. *Mol Phylogenet Evol* 25 (2):267-277

Guerrero PC, Rosas M, Arroyo MTK, Wiens JJ (2013) Evolutionary lag times and recent origin of the biota of an ancient desert (Atacama–Sechura). *Proc Natl Acad Sci USA* 110 (28):11469-11474

Guo Z, Sun B, Zhang Z, Peng S, Xiao G, Ge J, Hao Q, Qiao Y, Liang M, Liu J (2008) A major reorganization of Asian climate by the early Miocene. *Climate of the Past* 4 (3):153-174

Haffer J (2008) Hypotheses to explain the origin of species in Amazonia. *Braz J Biol* 68 (4 Suppl.):917-947

Harris RB, Birks SM, Leaché AD (2014) Incubator birds: biogeographical origins and evolution of underground nesting in megapodes (Galliformes: Megapodiidae). *J Biogeogr* 41 (11):2045-2056

Harrison SP, Prentice CI (2003) Climate and CO2 controls on global vegetation distribution at the last glacial maximum: analysis based on palaeovegetation data, biome modelling and palaeoclimate simulations. *Glob Change Biol* 9 (7):983-1004

Hawkins BA, Diniz-Filho JAF, Jaramillo CA, Soeller SA (2006) Post-Eocene climate change, niche conservatism, and the latitudinal diversity gradient of New World birds. *J Biogeogr* 33:770-780

Hawkins BA, Diniz-Filho JAF, Jaramillo CA, Soeller SA (2007) Climate, Niche Conservatism, and the Global Bird Diversity Gradient. *Am Nat* 170 (Supplement):S16-S27

Hawkins BA, Porter EE, Felizola Diniz-Filho JAF (2003) Productivity and history as predictors of the latitudinal diversity gradient of terrestrial birds. *Ecology* 84 (6):1608-1623

Hernández Fernández M, Álvarez-Sierra M, Peláez-Campomanes P (2007) Bioclimatic analysis of rodent palaeofaunas reveals severe climatic changes in Southwestern Europe during the Plio-Pleistocene. *Palaeogeogr Palaeoclimatol Palaeoecol* 251:500 - 526

Hernández Fernández M, Vrba ES (2005) Macroevolutionary processes and biomic specialization: testing the resource-use hypothesis. *Evol Ecol* 19:199-119

Hewitt G (2000) The genetic legacy of the Quaternary ice ages. *Nature* 405:907-913

Hewitt G (2003) Ice ages: their impact on species distributions and evolution. *Evolution on Planet Earth*:339 - 361

Holdridge LR (1967) *Life zone ecology*. Tropical Science Center, San Jose, Costa Rica.

Hooghiemstra H (1989) Quaternary and Upper-Pliocene glaciations and forest development in the tropical Andes: evidence from a long high-resolution pollen record from the sedimentary basin of Bogotá, Colombia. *Palaeogeogr Palaeoclimatol Palaeoecol* 72:11-26

Hooghiemstra H, Cleef AM, Churchill SP, Balslev H, Forero E, Luteyn JL (1993) Pleistocene climatic change and environmental and generic dynamics in the North Andean montane forest and páramo. In: *Biodiversity and conservation of Neotropical montane forests*. Proceedings of a symposium, New York Botanical Garden, pp 35-49

Hooghiemstra H, Van der Hammen T (2004) Quaternary Ice-Age dynamics in the Colombian Andes: developing an understanding of our legacy. *Philos Trans R Soc B* 359 (1442):173-181

Hoorn C, Flantua S (2015) An early start for the Panama land bridge. *Science* 348 (6231):186-187

Hoorn C, Wesselingh FP, ter Steege H, Bermudez MA, Mora A, Sevink J, Sanmartin I, Sanchez-Meseguer A, Anderson CL, Figueiredo JP, Jaramillo CA, Riff D, Negri FR, Hooghiemstra H, Lundberg J, Stadler T, Sarkinen T, Antonelli A (2010) Amazonia through time: Andean uplift, climate change, landscape evolution, and biodiversity. *Science* 330:927 - 931

Huang Z, Liu N, Xiao Ya, Cheng Y, Mei W, Wen L, Zhang L, Yu X (2009) Phylogenetic relationships of four endemic genera of the Phasianidae in China based on mitochondrial DNA control-region genes. *Mol Phylogenet Evol* 53 (2):378-383

Hugall AF, Stuart-Fox D (2012) Accelerated speciation in colour-polymorphic birds. *Nature* 485 (7400):631-634

Humphreys AM, Linder HP (2013) Evidence for recent evolution of cold tolerance in grasses suggests current distribution is not limited by (low) temperature. *New Phytol* 198 (4):1261-1273

Hwang SH, Mayr G, Bolortsetseg M (2010) The earliest galliform bird in Asia, from the Late Paleocene-Early Eocene of the Gobi Desert, Mongolia. *J Vertebr Paleontol* 30:1642-1644

Ivanov D, Utescher T, Mosbrugger V, Syabryaj S, Djordjević-Milutinović D, Molchanoff S (2011) Miocene vegetation and climate dynamics in Eastern and Central Paratethys (Southeastern Europe). *Palaeogeogr Palaeoclimatol Palaeoecol* 304 (3):262-275

Jacobs BF (2004) Palaeobotanical studies from tropical Africa: relevance to the evolution of forest, woodland and savannah biomes. *Philos Trans R Soc B* 359 (1450):1573-1583

Jansson R (2003) Global patterns in endemism explained by past climatic change. *Proc R Soc B* 270:583 - 590

Janis CM (1993) Tertiary Mammal evolution in the context of changing climates, vegetation, and tectonic events. *Annu Rev Ecol Syst* 24:467-500

Janzen DH (1967) Why mountain passes are higher in the tropics. *Am Nat*:233-249

Jara-Arancio P, Arroyo MTK, Guerrero PC, Hinojosa LF, Arancio G, Méndez MA (2014) Phylogenetic perspectives on biome shifts in *Leucocoryne* (Alliaceae) in relation to climatic niche evolution in western South America. *J Biogeogr* 41 (2):328-338

Jaramillo CA (2012) Historia geológica del bosque húmedo neotropical. *Rev Acad Colomb Cienc* 36 (138):59-80

Jaramillo CA, Cárdenas A (2013) Global warming and neotropical rainforests: A historical perspective. *Annu Rev Earth Pl Sc* 41:741-766

Jaramillo CA, Ochoa D, Contreras L, Pagani M, Carvajal-Ortiz H, Pratt LM, Krishnan S, Cardona A, Romero M, Quiroz L, Rodríguez G, Rueda MJ, de la Parra F, Morón S, Green W, Bayona G, Montes C, Quintero O, Ramírez R, Mora G, Schouten S, Bermúdez H, Navarrete R, Parra F, Alvarán M, Osorno J, Crowley JL, Valencia V, Vervoort J (2010) Effects of rapid global warming

at the Paleocene-Eocene boundary on Neotropical vegetation. *Science* 330:957 - 961

Jaramillo CA, Rueda MJ, Mora G (2006) Cenozoic plant diversity in the Neotropics. *Science* 311:1893-1896

Jarvis ED, Mirarab S, Aberer AJ, Li B, Houde P, Li C, Ho SYW, Faircloth BC, Nabholz B, Howard JT, Suh A, Weber CC, da Fonseca RR, Li J, Zhang F, Li H, Zhou L, Narula N, Liu L, Ganapathy G, Boussau B, Bayzid MS, Zavidovych V, Subramanian S, Gabaldón T, Capella-Gutiérrez S, Huerta-Cepas J, Rekepalli B, Munch K, Schierup M, Lindow B, Warren WC, Ray D, Green RE, Bruford MW, Zhan X, Dixon A, Li S, Li N, Huang Y, Derryberry EP, Bertelsen MF, Sheldon FH, Brumfield RT, Mello CV, Lovell PV, Wirthlin M, Schneider MPC, Prosdocimi F, Samaniego JA, Velazquez AMV, Alfaro-Núñez A, Campos PF, Petersen B, Sicheritz-Ponten T, Pas A, Bailey T, Scofield P, Bunce M, Lambert DM, Zhou Q, Perelman P, Driskell AC, Shapiro B, Xiong Z, Zeng Y, Liu S, Li Z, Liu B, Wu K, Xiao J, Yinqi X, Zheng Q, Zhang Y, Yang H, Wang J, Smeds L, Rheindt FE, Braun M, Fjeldså J, Orlando L, Barker FK, Jønsson KA, Johnson W, Koepfli K-P, O'Brien S, Haussler D, Ryder OA, Rahbek C, Willerslev E, Graves GR, Glenn TC, McCormack J, Burt D, Ellegren H, Alström P, Edwards SV, Stamatakis A, Mindell DP, Cracraft J, Braun EL, Warnow T, Jun W, Gilbert MTP, Zhang G (2014) Whole-genome analyses resolve early branches in the tree of life of modern birds. *Science* 346 (6215):1320-1331.

Jetz W, Fine PVA (2012) Global gradients in vertebrate diversity predicted by historical area-productivity dynamics and contemporary environment. *PLoS Biol* 10 (3):e1001292.

Jetz W, Thomas HH, Joy JB, Hartman K, Mooers AO (2012) The global diversity of birds in space and time. *Nature* 491 (7424):444-448

Jocque M, Field R, Brendonck L, De Meester L (2010) Climatic control of dispersal: ecological specialization trade-offs: a metacommunity process at the heart of the latitudinal diversity gradient? *Glob Ecol Biogeogr* 19 (2):244-252

Kahlke R-D (2014) The origin of Eurasian Mammoth Faunas (*Mammuthus - Coelodonta* Faunal Complex). *Quat Sci Rev* 96:32-49

Kemp AC, Crowe TM (1994) Morphometrics of falconets and hunting behaviour of the Black-thighed Falconet *Microhierax fringillarius*. *Ibis* 136 (1):44-49

Kimball RT, Mary CMS, Braun EL (2011) A macroevolutionary perspective on multiple sexual traits in the Phasianidae (Galliformes). *Int J Evol Biol* 2011

Klaassen M (1996) Metabolic constraints on long-distance migration in birds. *J Exp Biol* 199:57-64

Kohfeld KE, Harrison SP (2000) How well can we simulate past climates? Evaluating the models using global palaeoenvironmental datasets. *Quat Sci Rev* 19 (1):321-346

Koufos GD, Kostopoulos DS, Vlachou TD (2005) Neogene/Quaternary mammalian migrations in Eastern Mediterranean. *Belg J Zool* 135 (2):181-190

Latorre C, Quade J, McIntosh WC (1997) The expansion of C 4 grasses and global change in the late Miocene: stable isotope evidence from the Americas. *Earth Planet Sci Lett* 146 (1):83-96

Lavin M, Herendeen PS, Wojciechowski MF (2005) Evolutionary rates analysis of Leguminosae implicates a rapid diversification of lineages during the Tertiary. *Syst biol* 54 (4):575-594

Le Roux JP (2012) A review of Tertiary climate changes in southern South America and the Antarctic Peninsula. Part 2: continental conditions. *Sedimentary Geology* 247:21-38

Lecompte E, Aplin K, Denys C, Catzeflis F, Chades M, Chevret P (2008) Phylogeny and biogeography of African Murinae based on mitochondrial and nuclear gene sequences, with a new tribal classification of the subfamily. *BMC Evol Biol* 8 (1):199

Lei F, Qu Y, Song G (2014) Species diversification and phylogeographical patterns of birds in response to the uplift of the Qinghai-Tibet Plateau and Quaternary glaciations. *Current Zoology* 60:149-161

Li C-K, Lin Y-P, Gu Y-M, Hou L-H, Wu W-Y, Qiu ZD (1983) The Aragonian vertebrate fauna of Xiacaowan, Jiangsu. *Vertebrat PalAsiatic* 21 (4):313-327

Li Z, Zhou Z, Deng T, Li Q, Clarke JA (2014) A falconid from the Late Miocene of northwestern China yields further evidence of transition in Late Neogene steppe communities. *The Auk* 131 (3):335-350

Lindow BEK, Dyke GJ (2006) Bird evolution in the Eocene: climate change in Europe and a Danish fossil fauna. *Biol Rev* 81:483-499

Liu L, Eronen JT, Fortelius M (2009) Significant mid-latitude aridity in the middle Miocene of East Asia. *Palaeogeogr Palaeoclimatol Palaeoecol* 279 (3):201-206

Lloyd P (1999) Rainfall as a breeding stimulus and clutch size determinant in South African arid-zone birds. *Ibis* 141 (4):637-643

Lu X, Zheng G, Gu B (1997) A preliminary investigation on taxonomy, distribution and evolutionary relationship of the eared pheasants, *Crossoptilon*. *Acta Zool Sinica* 44 (2):131-137

Lundberg JG, Marshall LG, Guerrero J, Horton B, Malabarba M, Wesselingh F (1998) The stage for Neotropical fish diversification: a history of tropical South American rivers. *Phylogeny and classification of Neotropical fishes*:13-48

Marincovich L, Gladenkov AY (2001) New evidence for the age of Bering Strait. *Quat Sci Rev* 20:329-335

Markgraf V, McGlone M, Hope G (1995) Neogene paleoenvironmental and paleoclimatic change in southern temperate ecosystems: a southern perspective. *Trends Ecol Evol* 10:143 - 147

Martin H (2006) Cenozoic climatic change and the development of the arid vegetation in Australia. *J Arid Environ* 66 (3):533-563

Martínez-Navarro B (2010) Early Pleistocene faunas of Eurasia and hominin dispersals. In:Fleagle JG, Shea JJ, Frederick EG et al.(eds) *Out of Africa I*. Springer, pp 207-224

Masman D, Daan S, Dietz M (1989) Heat increment of feeding in the kestrel, *Falco tinnunculus*, and its natural seasonal variation. In: Bech C, Eidsmo R.(eds) *Physiology of cold adaptation in birds*. Springer, pp 123-135

Matzke NJ (2013) *BioGeoBEARS: BioGeography with Bayesian (and likelihood) Evolutionary Analysis in R Scripts*.http://cran.r-project.org/web/packages/BioGeoBEARS/. Accessed February 2015

Matzke NJ (2014a) Model selection in historical biogeography reveals that founder-event speciation is a crucial process in island clades. *Syst biol*:syu056

Matzke NJ (2014b) *Package "BioGeoBEARS" BioGeography with Bayesian (and Likelihood) Evolutionary Analysis in R scripts*. Version 0.2.1 edn

Mayr G (2009) *Paleogene fossil birds*. Springer, Heilderberg

Mayr G, De Pietri VL (2014) Earliest and first Northern Hemispheric hoatzin fossils substantiate Old World origin of a "Neotropic endemic". *Naturwissenschaften* 101:143-148

Mayr G, Weidig I (2004) The Early Eocene bird *Gallinuloides wyomingensis*: a stem group representative of Galliformes. *Acta Palaeontol Pol* 49 (2):211-217

McNab BK (2009) Ecological factors affect the level and scaling of avian BMR. *Comp Biochem Physiol A* 152 (1):22-45

Meijaard E (2003) Mammals of south-east Asian islands and their Late Pleistocene environments. *J Biogeogr* 30 (8):1245-1257

Mendoza ÁM, Ospina OE, Cárdenas-Henao H, García-R JC (2015) A likelihood inference of historical biogeography in the world's most diverse terrestrial vertebrate genus: Diversification of direct-developing frogs (Craugastoridae: *Pristimantis*) across the Neotropics. *Mol Phylogenet Evol* 85:50-58

Meredith RW, Janecka JE, Gatesy J, Ryder OA, Fisher CA, Teeling EC, Goodbla A, Eizirik E, Simão TL, Stadler T, Rabosky DL, Honeycutt RL, Flynn JJ, Ingram CM, Steiner C, Williams TL, Robinson TJ, Burk-Herrick A, Westerman M, Ayoub NA, Springer MS, Murphy WJ (2011) Impacts of the Cretaceous Terrestrial Revolution and KPg Extinction on Mammal Diversification. *Science* 334:521-524.

Miao Y, Herrmann M, Wu F, Yan X, Yang S (2012) What controlled Mid–Late Miocene long-term aridification in Central Asia?: Global cooling or Tibetan Plateau uplift: A review. *Earth-Science Reviews* 112 (3):155-172

Mlíkovský Jí (1996) Tertiary avian faunas of Europe. *Acta Univ Carol Geol* 39:777-818

Mlíkovský Jí (2002) *Cenozoic Birds of the World*, vol Part 1: Europe. Praha: Ninox press

Montes C, Bayona G, Cardona A, Buchs DM, Silva CA, Morón S, Hoyos N, Ramírez DA, Jaramillo CA, Valencia V (2012) Arc-continent collision and orocline formation: Closing of the Central American seaway. *J of Geophys Res: Solid Earth* 117 (B4):B04105.

Montes C, Cardona A, Jaramillo CA, Pardo A, Silva J, Valencia V, Ayala C, Pérez-Angel L, Rodríguez-Parra L, Ramírez V (2015) Middle Miocene closure of the Central American Seaway. *Science* 348 (6231):226-229

Mourer-Chauviré (1992) The Galliformes (Aves) from the Phosphorites du Quercy (France): systematics and biostratigraphy. In: Campbell KE (ed) *Papers in avian paleontology honoring Pierce Brodkorb*, vol 36. Nat Hist Mus Los Angeles Cty Sci Ser, pp 67-95

Nores M (2004) The implications of Tertiary and Quaternary sea level rise events for avian distribution patterns in the lowlands of northern South America. *Glob Ecol Biogeogr* 13:149-161

Noriega JI, Areta JI, Vizcaíno SF, Bargo MS (2011) Phylogeny and taxonomy of the patagonian Miocene falcon *Thegornis musculosus* Ameghino, 1895 (Aves: Falconidae). *J Paleontol* 85 (6):1089-1104

Ogasawara K (1998) Review and comments on late Neogene climatic fluctuations and intermittence of Bering Land Bridge. *J Asian Earth Sci* 16 (1):45-48

Olson SL (1985) The fossil record of birds. In: Farner DS, King JR, Parkes KC (eds) *Avian Biology*, vol 8. Academic Press, NewYork, pp 79-238

Ortiz-Jaureguizar E, Cladera GA (2006) Paleoenvironmental evolution of southern South America during the Cenozoic. *J Arid Environ* 66:498-532

Pelegrin JS (2009) *Especialización biómica en las aves rapaces (Falconiformes y Strigiformes) y procesos macroevolutivos a escala global*. M.Sc. Thesis, Universidad Complutense de Madrid, Spain

Pelegrin JS, Cantalapiedra JL, Hernández Fernández M (2015) The macroevolutionary role of migration for bird occupation of biomes with

adverse climatic conditions. In: Domingo L, Domingo MS, Fesharaki O et al. (eds) *Current trends in Paleontology and Evolution*. Madrid-Spain., pp 197-199

Pennington RT, Cronk QC, Richardson JA (2004a) Introduction and synthesis: plant phylogeny and the origin of major biomes. *Philos Trans R Soc B*: 359 (1450):1455-1464

Pennington RT, Lavin M, Prado DE, Pendry CA, Pell SK, Butterworth CA (2004b) Historical climate change and speciation: neotropical seasonally dry forest plants show patterns of both Tertiary and Quaternary diversification. *Philos Trans R Soc B* 359 (1443):515-538

Pennington RT, Prado DE, Pendry CA (2000) Neotropical seasonally dry forests and Quaternary vegetation changes. *J Biogeogr* 27:261 - 273

Pennington RT, Ratter JA, Lewis GP (2006) An overview of the plant diversity, biogeography and conservation of neotropical savannas and seasonally dry forests. In: Pennington RT, Lewis GP, Ratter JA.(eds) *Neotropical savannas and seasonally dry forests: plant biodiversity, biogeography and conservation*.1 - 29

Peterson AT, Nyari AS (2008) Ecological niche conservatism and Pleistocene Refugia in the Thrush-like Mourner, *Schiffornis sp*., In the Neotropics. *Evolution* 62 (1):173-183

Peterson AT, Soberón J, Sánchez-Cordero V (1999) Conservatism of ecological niches in evolutionary time. *Science* 285:1265-1267

Pickford M (1992) Evidence for an arid climate in western Uganda during the middle Miocene. *Comptes Rendus Acad des Sci serie II* 315 (11):1419-1424

Pigot AL, Tobias JA (2013) Species interactions constrain geographic range expansion over evolutionary time. *Ecol Lett* 16 (3):330-338

Pigot AL, Tobias JA (2015) Dispersal and the transition to sympatry in vertebrates. *Proc R Soc Lond B* 282 (1799):20141929

Plana V (2004) Mechanisms and tempo of evolution in the African Guineo–Congolian rainforest. *Philos Trans R Soc B* 359 (1450):1585-1594

Popova S, Utescher T, Gromyko D, Bruch A, Mosbrugger V (2012) Palaeoclimate evolution in Siberia and the Russian Far East from the Oligocene to Pliocene–evidence from fruit and seed floras. *Turkish J Earth Sci* 21 (2):315-334

Potts R, Behrensmeyer A (1992) Late Cenozoic terrestrial ecosystems. *Terrestrial Ecosystems trough Time*:419 - 541

Pound MJ, Haywood AM, Salzmann U, Riding JB (2012) Global vegetation dynamics and latitudinal temperature gradients during the Mid to Late Miocene (15.97–5.33 Ma). *Earth-Sci Rev* 112 (1):1-22

Pound MJ, Haywood AM, Salzmann U, Riding JB, Lunt DJ, Hunter SJ (2011) A Tortonian (late Miocene, 11.61–7.25 Ma) global vegetation reconstruction. *Palaeogeogr Palaeoclimatol Palaeoecol* 300 (1):29-45

Poux C, Chevret P, Huchon D, De Jong WW, Douzery EJ (2006) Arrival and diversification of caviomorph rodents and platyrrhine primates in South America. *Syst Biol* 55 (2):228-244

Price JP, Clague DA (2002) How old is the Hawaiian biota? Geology and phylogeny suggest recent divergence. *Proc R Soc Lond B* 269 (1508):2429-2435

Pyron RA, Burbrink FT (2012) Extinction, ecological opportunity, and the origins of global snake diversity. *Evolution* 66 (1):163-178

Qu Y, Lei F, Zhang R, Lu X (2010) Comparative phylogeography of five avian species: implications for Pleistocene evolutionary history in the Qinghai-Tibetan plateau. *Mol Ecol* 19 (2):338-351

Quintero E, Ribas CC, Cracraft J (2013) The Andean *Hapalopsittaca* parrots (Psittacidae, Aves): an example of montane-tropical lowland vicariance. *Zool Scr* 42 (1):28-43.

Raes N, Cannon CH, Hijmans RJ, Piessens T, Saw LG, van Welzen PC, Slik JF (2014) Historical distribution of Sundaland's Dipterocarp rainforests at Quaternary glacial maxima. *Proc Natl Acad Sci USA* 111 (47):16790-16795

Randi E, Lucchini V, Hennache A, Kimball RT, Braun EL, Ligon JD (2001) Evolution of the mitochondrial DNA control region and cytochrome b genes and the inference of phylogenetic relationships in the avian genus *Lophura* (Galliformes). *Mol Phylogenet Evol* 19 (2):187-201

Ree RH, Smith SA (2008) Maximun likelihood inference of geographic range evolution by dispersal, local extinction and cladogenesis. *Syst Biol* 57 (1):4-14

Renjifo LM, Servat GP, Goerck JM, Loiselle BA, Blake JG (1997) Patterns of species composition and endemism in the northern neotropics: a case for conservation of montane avifaunas. *Ornithological Monographs* 48:577-594

Retallack GJ (1992) Paleosols and changes in climate across the Eocene/Oligoncene boundary. In: Prothero DR, Berggren WA (eds) *Eocene-Oligocene climatic and biotic evolution*. Princeton University Press, Princeton, pp 382-398

Ribas CC, Aleixo A, Nogueira ACR, Miyaki CY, Cracraft J (2011) A palaeobiogeographic model for biotic diversification within Amazonia over the past three million years. *Proc R Soc Lond B*: 1-9

Ribas CC, Miyaki CY, Cracraft J (2009) Phylogenetic relationships, diversification and biogeography in Neotropical *Brotogeris* parakeets. *J Biogeogr* 36 (9):1712-1729.

Rich PV, Hou LH, Ono K, Baird RF (1986) A review of the fossil birds of China, Japan and Southeast Asia. *Geobios* 19 (6):755-772

Riddle B, Hafner D (2006) A step-wise approach to integrating phylogeographic and phylogenetic biogeographic perspectives on the history of a core North American warm deserts biota. *J Arid Environ* 66 (3):435-461

Rolland J, Jiguet F, Jønsson KA, Condamine FL, Morlon H (2014) Settling down of seasonal migrants promotes bird diversification. *Proc R Soc Lond B* 281 (1784).

Salisbury CL, Seddon N, Cooney CR, Tobias JA (2012) The latitudinal gradient in dispersal constraints: ecological specialisation drives diversification in tropical birds. *Ecol Lett* 15 (8):847-855

Salzmann U, Haywood AM, Lunt D, Valdes P, Hill D (2008) A new global biome reconstruction and data-model comparison for the middle Pliocene. *Glob Ecol Biogeogr* 17 (3):432-447

Sánchez Marco A (1999) Catalogo paleornitológico del Terciario ibérico y balear. *Estud Geo*l 55:163-171

Sánchez Marco A (2004) Avian zoogeographical patterns during the Quaternary in the Mediterranean Region and paleoclimatic interpretation. *Ardeola* 51 (1):91-132

Sanmartín I, Enghoff H, Ronquist F (2001) Patterns of animal dispersal, vicariance and diversification in the Holartic. *Biol J Linn Soc* 73:345-390

Scotese CR (2001) Atlas of Earth history-PALEOMAP project. http://www.scotese.com/.

Senut B, Pickford M, Ségalen L (2009) Neogene desertification of Africa. *Comptes Rendus Geosci* 341:591-602

Sepulchre P, Ramstein G, Fluteau F, Schuster M, Tiercelin J-J, Brunet M (2006) Tectonic uplift and Eastern Africa aridification. *Science* 313 (5792):1419-1423

Shi Y, Tang M, Ma Y (1999) Linkage between the second uplifting of the Qinghai-Xizang (Tibetan) Plateau and the initiation of the Asian monsoon system. *Sci China Ser D* 42 (3):303-312

Smith MF, Patton JL (1999) Phylogenetic relationships and the radiation of sigmodontine rodents in South America: evidence from cytochrome b. *J Mamm Evol* 6 (2):89-128

Spicer RA, Harris NB, Widdowson M, Herman AB, Guo S, Valdes PJ, Wolfe JA, Kelley SP (2003) Constant elevation of southern Tibet over the past 15 million years. *Nature* 421 (6923):622-624

Stein RW (2013) *Multistage Scenarios for the Evolution of Polymorphisms in Birds*. Ph.D Thesis. Simon Fraser, Burnaby, British Columbia, Canada

Stein RW, Brown JW, Mooers AØ (2015) A molecular genetic time scale demonstrates Cretaceous origins and multiple diversification rate shifts within the order Galliformes (Aves). *Mol Phylogenet Evol* 92:155-164

Strahler AN, Strahler AH (1987) *Modern Physical Geography*. John Wiley y Sons, New York

Strömberg CA, McInerney FA (2011) The Neogene transition from C3 to C4 grasslands in North America: assemblage analysis of fossil phytoliths. *Paleobiology* 37 (1):50-71

Sweet AD, Johnson KP (2014) Patterns of diversification in small New World ground doves are consistent with major geologic events. *The Auk* 132 (1):300-312

Tambussi CP, Degrange FJ (2013) South American and Antarctic continental Cenozoic Birds. In: Lohmann G, Mysak LA, Notholt J, Rabassa J, Unnithan V (eds) *South America and the Southern Hemisphere*. Springer, New York, p 111

Tambussi CP, Noriega JI, Santillana S, Marenssi S (1995) Falconid bird from the middle Eocene La Meseta Formation, Seymour Island, West Antarctica. *J Vertebr Paleontol* 15 (554)

Thorup K (2006) Does the migration constrain dispersal and range sizes of migratory birds? *J Biogeogr* 33:1166-1171

Tieleman BI, Williams JB, Buschur ME, Brown CR (2003) Phenotypic variation of larks along an aridity gradient: are desert birds more flexible? *Ecology* 84 (7):1800-1815

Toussaint EFA, Condamine FL, Kergoat GJ, Caodevielle-Dulac C, Barbut J, Silvain JF, Le Ru BP (2012) Palaeoenviromental shifts drove the adaptive radiation of a noctuid stemborer tribe (Lepidoptera, Noctuidae, Apameini) in the Miocene. *PLoS ONE* 7 (7):1-15

Uliana M, Biddle K (1988) Mesozoic-Cenozoic paleogeographic and geodynamic evolution of southern South America. *Rev Bras Geo* 18 (2):172-190

Valderrama E, Pérez-Emán JL, Brumfield RT, Cuervo AM, Cadena CD (2014) The influence of the complex topography and dynamic history of the montane Neotropics on the evolutionary differentiation of a cloud forest bird (*Premnoplex brunnescens*, Furnariidae). *J Biogeogr* 41 (8):1533-1546

Valdes PJ (2000) South American palaeoclimate model simulations: how reliable are the models? *J Quat Sci* 15 (4):357-368

van Dam JA (2006) Geographic and temporal patterns in the late Neogene (12–3 Ma) aridification of Europe: the use of small mammals as paleoprecipitation proxies. *Palaeogeogr Palaeoclimatol Palaeoecol* 238 (1):190-218

van der Made J (1999) Intercontinental relatioship Europe-Africa and the Indian Subcontinent. In: Rössner G, Heissig K (eds) *The Miocene Land Mammals of Europe*. Verlag Dr Friedrich Pfeil, München, pp 359-364

Vieites DR, Min M-S, Wake DB (2007) Rapid diversification and dispersal during periods of global warming by plethodontid salamanders. *Proc Natl Acad Sci USA* 104 (50):19903-19907

Voris HK (2000) Maps of Pleistocene sea levels in Southeast Asia: shorelines, river systems and time durations. *J Biogeogr* 27 (5):1153-1167

Vrba ES (1992) Mammals as a key to evolutionary theory. *J Mammal* 73:1-28

Vrba ES (1995) On the connections between paleoclimate and evolution. In: Vrba ES, Denton GH, Partridge TC, Burckle LH (eds) *Paleoclimate and Evolution, with Emphasis of Human Origins*. Yale University Press, New Haven, USA, pp 24-45

Walter H (1970) *Vegetationszonen und klima.* Eugen Ulmer, Stuttgart

Wang N, Kimball RT, Braun EL, Liang B, Zhang Z (2013) Assessing phylogenetic relationships among Galliformes: a multigene phylogeny with expanded taxon sampling in Phasianidae. *PloS ONE* 8 (5):e64312

Wang Q, Song Z, Chen Y, Shen S, Li Z (2014) Leaves and fruits of *Bauhinia* (Leguminosae, Caesalpinioideae, Cercideae) from the Oligocene Ningming Formation of Guangxi, South China and their biogeographic implications. *BMC Evol Biol* 14 (1):88

Wang X, Zattin M, Li J, Song C, Peng T, Liu S, Liu B (2011) Eocene to Pliocene exhumation history of the Tianshui-Huicheng region determined by Apatite fission track thermochronology: Implications for evolution of the northeastern Tibetan Plateau margin. *J Asian Earth Sci* 42 (1):97-110

Wang WM (2004) On the origin and development of *Artemisia* (Asteraceae) in the geological past. *Bot J Linn Soc* 145 (3):331-336

Wang Y, Cerling TE, MacFadden BJ (1994) Fossil horses and carbon isotopes: new evidence for Cenozoic dietary, habitat, and ecosystem changes in North America. *Palaeogeogr Palaeoclimatol Palaeoecol* 107 (3):269-279

Warren BH, Strasberg D, Bruggemann JH, Prys-Jones R, Thébaud C (2010) Why does the biota of the Madagascar region have such a strong Asiatic flavour? *Cladistics* 26:526-538

Weir JT, Bermingham E, Schluter D (2009) The Great American Biotic Interchange in birds. *Proc Natl Acad Sci USA* 106 (51):21737-21742.

Weir JT, Schluter D (2004) Ice sheets promote speciation in boreal birds. *Proc R Soc Lond B* 271 (1551):1881-1887.

Wen L, Liu N (2010) Cytochrome b gene based phylogeny and genetic divergence of *Tetraophasis* of China. *Anim Biol* 60 (2):133-144

Werneck FP (2011) The diversification of eastern South American open vegetation biomes: historical biogeography and perspectives. *Quat Sci Rev* 30:1630 - 1648

Werneck FP, Costa GC, Colli GR, Prado D, Sites JW (2011) Revisiting the historical distribution of Seasonally Dry Tropical Forests: new insights based on palaeodistribution modelling and palynological evidence. *Global Ecol Biogeogr* 20:272 - 288

Wesselingh F, Salo J (2006) A Miocene perspective on the evolution of the Amazonian biota. *Scripta Geologica* 133:439-458

Wetmore A (1930) Two fossil birds from the Miocene of Nebraska. *Condor*:152-154

Whittaker RH (1975) *Communities and Ecosystems*. 2nd edn. Macmillan, New York

Wiens JJ (2004) Speciation and ecology revisited: phylogenetic niche conservatism and the origin of species. *Evolution* 58 (1):193-197

Wiens JJ, Ackerly DD, Allen AP, Anacker BL, Buckley LB, Cornell HV, Damschen EI, Davies TJ, Grytnes J-A, Harrison SP, Hawkins BA, Holt RD, McCain CM, Stephens PR (2010) Niche conservatism as an emerging principle in ecology and conservation biology. *Ecol Lett* 13:1310-1324

Williams SE, Pearson RG (1997) Historical rainforest contraction, localized extinctions and patterns of vertebrate endemism in the rainforest of Australia′s wet tropics. *Proc R Soc Lond B* 264:709-716

Wolfe JA (1985) Distribution of Major Vegetational Types During the Tertiary. In: Sundquist ET, Broecker WS (eds) *The Carbon Cycle and Atmospheric CO2:*

Natural Variations Archean to Present. American Geophysical Union, pp 357-375.

Woodruff DS (2010) Biogeography and conservation in Southeast Asia: how 2.7 million years of repeated environmental fluctuations affect today's patterns and the future of the remaining refugial-phase biodiversity. *Biodivers Conserv* 19 (4):919-941

Woodward F, Lomas M, Kelly C (2004) Global climate and the distribution of plant biomes. *Philos Trans R Soc B* 359 (1450):1465-1476

Yang S, Dong H, Lei F (2009) Phylogeography of regional fauna on the Tibetan Plateau: a review. *Prog Nat Sci* 19 (7):789-799

Yao Y-F, Bruch AA, Mosbrugger V, Li C-S (2011) Quantitative reconstruction of Miocene climate patterns and evolution in Southern China based on plant fossils. *Palaeogeogr Palaeoclimatol Palaeoecol* 304 (3):291-307

Yoder A, Nowak M (2006) Has Vicariance or Dispersal Been the Predominant Biogeographic Force in Madagascar? Only Time Will Tell. *Annu Rev Ecol Evol Syst* 37:405-431

Zachos J, Pagani M, Sloan L, Thomas E, Billups K (2001) Trends, rhythms, and aberrations in global climate 65 Ma to Present. *Science* 292 (686-693)

Zachos JC, Dickens GR, Zeebe RE (2008) An early Cenozoic perspective on greenhouse warming and carbon-cycle dynamics. *Nature* 451 (7176):279-283

Zelenkov N (2009) Phylogenetic analysis of some Neogene phasianid genera (Aves: Phasianidae). *Paleontol J* 43 (4):438-443

Zheng H, Powell CM, Rea DK, Wang J, Wang P (2004) Late Miocene and mid-Pliocene enhancement of the East Asian monsoon as viewed from the land and sea. *Global Planet Change* 41 (3):147-155

Zhisheng A, Kutzbach JE, Prell WL, Porter SC (2001) Evolution of Asian monsoons and phased uplift of the Himalaya-Tibetan plateau since Late Miocene times. *Nature* 411 (6833):62-66

Zimov SA, Chuprynin V, Oreshko A, Chapin III F, Reynolds J, Chapin M (1995) Steppe-tundra transition: a herbivore-driven biome shift at the end of the Pleistocene. *Am Na*t:765-794

Zink RM, Blackwell RC (1998) Molecular systematics of the scaled quail complex (genus *Callipepla*). *The Auk*:394-403

Appendix 4.8.

Appendix 4.8.1. Table S1. Biome existence matrix

Table S1A. Since Pliocene-Pleistocene

Source	I	II	II/III	III	IV	V	VI	VII	VIII	IX
I	1	1	1	0	0	1	0	0	0	0
II	1	1	1	1	1	1	1	1	0	0
II/III	1	1	1	1	1	1	1	1	0	0
III	0	1	1	1	1	0	1	1	1	0
IV	0	1	1	1	1	1	1	1	1	0
V	1	1	1	0	1	1	1	0	1	0
VI	0	1	1	1	1	1	1	1	1	1
VII	0	1	1	1	1	0	1	1	1	1
VIII	0	0	0	1	1	1	1	1	1	1
IX	0	0	0	0	0	0	1	1	1	1

Table S1B. During Oligocene and Miocene

Source	I	II	II/III	III	IV	V	VI	VII	VIII	IX
I	1	1	1	0	0	1	0	0	0	0
II	1	1	1	0	0	1	1	0	0	0
II/III	1	1	1	0	0	1	1	0	0	0
III	0	0	0	0	0	0	0	0	0	0
IV	0	1	1	0	0	1	1	0	1	0
V	1	1	1	0	0	1	1	0	1	0
VI	0	1	1	0	0	1	1	0	1	0
VII	0	0	0	0	0	0	0	0	0	0
VIII	0	0	0	0	0	1	1	0	1	0
IX	0	0	0	0	0	0	0	0	0	0

Appendix 4.8.2. Table S2. 239 diverse biome occupation of non-passerine birds.

[1]]	[[21]]	[[41]]	[[61]]	[[81]]	[[101]]	[[121]]
I	VI VIII	II/III IV V	I II/III V	V VI VII VIII	II II/III IV VII	II V VI VIII
[[2]]	[[22]]	[[42]]	[[62]]	[[82]]	[[102]]	[[122]]
II	VI IX	VI VII VIII	III VII VIII	II IV VI VII	I II V VI	III IV V VII
[[3]]	[[23]]	[[43]]	[[63]]	[[83]]	[[103]]	[[123]]
IV	VII IX	II II/III III	I IV V	II II/III III IV	I II II/III IV	I II II/III IV V
[[4]]	[[24]]	[[44]]	[[64]]	[[84]]	[[104]]	[[124]]
VII	VII VIII	IV V VII	III VI VII	I II II/III III	V VI VII IX	II II/III III IV V
[[5]]	[[25]]	[[45]]	[[65]]	[[85]]	[[105]]	[[125]]
II/III	IV VII	V VI VIII	II IV VI	III IV V VI	II/III III IV VII	IV V VI VII VIII
[[6]]	[[26]]	[[46]]	[[66]]	[[86]]	[[106]]	[[126]]
IX	V VIII	V VI VII	III IV VI	IV V VII VIII	IV VI VIII IX	I II/III V VII VIII
[[7]]	[[27]]	[[47]]	[[67]]	[[87]]	[[107]]	[[127]]
V	IV V	II II/III IV	I II IV	III IV VI VII	II II/III VI VII	I II II/III V VIII
[[8]]	[[28]]	[[48]]	[[68]]	[[88]]	[[108]]	[[128]]
VIII	V VII	V VI IX	I V VII	II/III III IV V	III IV VI IX	II II/III III V VIII
[[9]]	[[29]]	[[49]]	[[69]]	[[89]]	[[109]]	[[129]]
VI	II III	IV V VI	II/III V VIII	IV VI VII VIII	I II III IV	I II IV V VI
[[10]]	[[30]]	[[50]]	[[70]]	[[90]]	[[110]]	[[130]]
III	I II/III	VI VIII IX	IV VI VIII	II II/III IV V	II V VI VII	II II/III V VII VIII
[[11]]	[[31]]	[[51]]	[[71]]	[[91]]	[[111]]	[[131]]
I V	III IV	VII VIII IX	II/III III VII	VI VII VIII IX	I II IV V	III V VI VIII IX
[[12]]	[[32]]	[[52]]	[[72]]	[[92]]	[[112]]	[[132]]
I II	II/III VII	II/III III IV	II IV V	I II V VII	II II/III V VII	I II II/III III V
[[13]]	[[33]]	[[53]]	[[73]]	[[93]]	[[113]]	[[133]]
II II/III	II VII	VI VII IX	II II/III7	I V VII VIII	II II/III V VI	I II VI VII VIII
[[14]]	[[34]]	[[54]]	[[74]]	[[94]]	[[114]]	[[134]]
II V	II VI	II III V	II III IV	II IV V VI	II II/III III V	II/III III V VI VII
[[15]]	[[35]]	[[55]]	[[75]]	[[95]]	[[115]]	[[135]]
VI VII	II/III V	V VII VIII	I II III	IV V VI VII	III VI VII VIII	II II/III III IV VII
[[16]]	[[36]]	[[56]]	[[76]]	[[96]]	[[116]]	[[136]]
V VI	IV VI VII	I V VIII	II/III VI IX	I II III V	I II II/III VII	I II II/III VII VIII
[[17]]	[[37]]	[[57]]	[[77]]	[[97]]	[[117]]	[[137]]
II/III IV	I II V	II V VIII	II/III IV VII	I II V VIII	IV V VII IX	I IV V VI VII
[[18]]	[[38]]	[[58]]	[[78]]	[[98]]	[[118]]	[[138]]
IV VI	I II II/III	II III VII	II/III III VI	II II/III V VIII	V VI VIII IX	IV VI VII VIII IX
[[19]]	[[39]]	[[59]]	[[79]]	[[99]]	[[119]]	[[139]]
II/III3	II II/III V	III IV VII	II VII VIII	II/III III IV VI	II III V VIII	II/III IV V VI VII
[[20]]	[[40]]	[[60]]	[[80]]	[[100]]	[[120]]	[[140]]
VIII IX	I V VI	II V VI	I II II/III V	II V VII VIII	IV V VI VIII	I III IV V VI

[[141]]	[[161]]	[[181]]	[[201]]	[[221]]
V VI VII VIII IX	I II V VI VII	I II IV V VI VII	I II II/III III IV V VII	II II/III III IV V VII VIII
[[142]]	[[162]]	[[182]]	[[202]]	[[222]]
I II V VII VIII	II IV V VII VIII	IV V VI VII VIII IX	II/III III IV V VI VII VIII	II III V VI VII VIII IX
[[143]]	[[163]]	[[183]]	[[203]]	[[223]]
II V VI VII VIII	II II/III III V VII	I II III IV V VI	I II II/III V VI VII VIII	II/III III IV V VI VII VIII IX
[[144]]	[[164]]	[[184]]	[[204]]	[[224]]
II/III III IV VI VII	II V VI VII IX	I II II/III V VI VII	I II V VI VII VIII IX	II III IV V VI VII VIII IX
[[145]]	[[165]]	[[185]]	[[205]]	[[225]]
III IV V VI VII	IV V VI VIII IX	II II/III IV V VII VIII	III IV V VI VII VIII IX	I II II/III III IV V VI VII
[[146]]	[[166]]	[[186]]	[[206]]	[[226]]
I II III V VI	I II V VI VIII	II/III III V VI VII IX	II/III III IV VI VII VIII IX	I II II/III V VI VII VIII IX
[[147]]	[[167]]	[[187]]	[[207]]	[[227]]
II/III V VI VII IX	I II II/III IV V VI	I II IV VI VII VIII	I II II/III III IV V VI	I II II/III III IV V VII VIII
[[148]]	[[168]]	[[188]]	[[208]]	[[228]]
I II/III IV V VII	II/III III IV V VI VII	III IV VI VII VIII IX	II II/III III IV V VI VII	I II III IV V VI VII VIII
[[149]]	[[169]]	[[189]]	[[209]]	[[229]]
II II/III IV V VI	II II/III III IV V VI	I II V VI VII VIII	I II/III IV V VI VII VIII	II II/III IV V VI VII VIII IX
[[150]]	[[170]]	[[190]]	[[210]]	[[230]]
II II/III III IV VI	II/III IV V VI VII VIII	II II/III V VI VII VIII	II II/III IV V VI VII VIII	I II II/III IV V VI VII VIII
[[151]]	[[171]]	[[191]]	[[211]]	[[231]]
I II II/III III IV	II II/III III V VII VIII	II II/III IV V VI VII	I II III IV V VI VII	II II/III III IV V VI VII VIII
[[152]]	[[172]]	[[192]]	[[212]]	[[232]]
I II II/III V VI	II II/III III IV VI VII	II III IV VI VII VIII	II II/III III V VI VII VIII	I II II/III III IV VI VII VIII
[[153]]	[[173]]	[[193]]	[[213]]	[[233]]
II II/III V VI VII	I II II/III V VII VIII	II IV V VI VII VIII	I II II/III IV V VI VII	I II II/III III V VI VII VIII
[[154]]	[[174]]	[[194]]	[[214]]	[[234]]
II/III III IV V VI	I II II/III III IV V	I II II/III IV V VIII	I II/III III IV V VI VII	II II/III III IV V VI VII IX
[[155]]	[[175]]	[[195]]	[[215]]	[[235]]
I V VI VII VIII	I II II/III III IV VII	II II/III IV VI VII VIII	I II II/III III V VII VIII	II II/III III V VI VII VIII IX
[[156]]	[[176]]	[[196]]	[[216]]	[[236]]
I II II/III V VII	II/III III IV VI VII VIII	I IV V VI VII VIII	I II II/III IV V VI VIII	I II II/III III IV V VI VII VIII
[[157]]	[[177]]	[[197]]	[[217]]	[[237]]
II III IV V VI	II II/III III IV V VII	I II II/III III V VI	I II II/III IV VI VII VIII	I II II/III III IV V VI VII IX
[[158]]	[[178]]	[[198]]	[[218]]	[[238]]
III IV VI VII VIII	I II II/III6 VII VIII	II II/III IV V VI VIII	II III IV V VI VII VIII	II II/III III IV V VI VII VIII IX
[[159]]	[[179]]	[[199]]	[[219]]	[[239]]
II II/III III VI VII	I V VI VII VIII IX	II IV VI VII VIII IX	I II II/III III IV V VIII	I II II/III III IV V VI VII VIII IX
[[160]]	[[180]]	[[200]]	[[220]]	
II II/III IV V VII	III IV V VI VII VIII	II IV V VI VIII IX	I II/III III IV VI VII VIII	

Appendix 4.8.3. Table S3. Biomes definition for each node in Galliformes based in probability values for each node. (I= Tropical rain forest; II= Tropical deciduous woodland; II/III= Savanna; III= Subtropical Desert ; IV= Sclerophyllous woodland-shrubland; V=Temperate evergreen forest; VI=Temperate broadleaf deciduous forest; VII= Steppe to cold desert; VIII=Boreal coniferous forest (Taiga);IX=Tundra).

Node	Probability of combinations until (50%)	Defined biomes
1	**II/III**=3.96; **II,II/III**=3.82; **II**=3.68; **I,II,II/III**=3.54; **I,II/III**=3.54 **II,II/III,V**=3.49; **I,II,II/III,V**=3.40; **II/III,V**=3.40; **I,II**=3.38; **II,V**=3.27; **II,II/III,V**,VI=3.25; **I II II/III V** VI=3.24; **I,II/III,V**=3.23; **I II V**=3.15; **I,II,V,**VI=3.01	I, II, II/III,V
2	II=14.02; II/III=12.88; V=10.41; VI=7.47; VIII=4.22; II,II/III=3.83	Indet.
3	**II**=20.81; **II/III**=19.94; **II,II/III**=6.57; V=6.45	II, II/III
4	**II/III**=29.74; **II**=25.61	II/III, II
5	**II/III**=28.25; II=20.67; V=9.42	II/III
6	**II/III**=35.45; II=22.34	II/III
7	**V**=32.89; I,**V**=24.42	V
8	**II**=34.74; I,**II**=16.66	II
9	**II**=64.98	II
10	**II**=61.85	II
11	**II**=49.15; **I,II**=25.93	II, I
12	**I,II**=40.66; **II**=26.84	II, I
13	**II**=54.47	II
14	**I,II**=45.46; **II**=28.50	II, I
15	**I,II**=45.86; **II**=29.60;	I, II
16	**I,II**=48.49; **II**=40.04	I,II
17	**II,V**=17.52; **V**=17.44; **II**=11.89; I,**II,V**=9.02	II, V
18	**V**=58.47	V
19	**V**=81.46	V
20	**V**=74.45	V
21	**V**=60.15	V
22	**V**=51.78	V
23	**V**=79.98	V
24	**I,V**=33.66; **V**=25.08	I,V
25	**I,II,V**=66.40	I, II, V
26	**II**=58.14	II
27	**I, II**=59.95	I, II
28	**V**=76.02	V
29	**V**=26.64; **I,V**=19.06; **I**,II/III,**V**=10.15	I, V
30	**V**=74.05	V
31	**V**=58.25	V
32	**II**=39.94; V=16.56	II
33	**II**=65.45	II
34	**II**=58.27	II
35	**II**=48.97; I,**II**=24.59	II
36	**II**=49.85; **II**,V=20.35	II
37	**II**=55.89	II
38	**II**=56.60	II
39	**I,II**=70.19	I, II
40	**II**=59.83	II
41	**II**=72.01	II
42	**II**=69.11	II
43	**II**=84.70	II
44	**II**=73.15	II
45	**II**=61.38	II

46	**I,II**=86.52	I, II
47	**II**=66.53	II
48	**II**=83.13	II
49	**II**=50.10	II
50	**II**=85.51	II
51	**II**=93.60	II
52	**II**=47.81; **I, II**=37.32	II, I
53	**II**=93.74	II
54	**I, II**=34.46; **II**=33.57	II, I
55	**II**=23.31; II/III=12.76;V=7.29; **II**,II/III=5.44; VI=5.42	II
56	**II/III**=28.42; II=16.33; I,**II/III**=7.36	II/III
57	**II/III**=39.11; II=23.32	II/III
58	**I,II/III**=20.76; **II/III**=17.91; **I**,II=12.60	I, II/III
59	**II/III**=36.91; II=22.63	II/III
60	**II**=34.53; II/III=14.56; V=9.35	II
61	II=22.32; II/III=14.32; V=9.56; VI=7.35	Indet.
62	**II/III**=19.76; II= 18.44; I, **II/III**=10.35	II/III
63	V=15.58; II=11.64; VI=11.57; II/III=5.19; II;V=4.48; V,VI=4.34	Indet.
64	**V**=26.76; VI=10.19; II=9.23;VIII=5.14	V
65	**V**=40.49; I,**V**=13.07	V
66	**V**=33.41; I,**V**=15.23; II=10.21	V
67	**I**,**V**=40.87; **V**=28.53	I, V
68	II=15.38; VI=15.33; V=11.09; II/III=7.34; II,VI=7.06	Indet.
69	**II**=22.66; II/III=12.33; VI=5.28; **II**,VI=4.64; **II**,II/III=4.64; I,**II**=3.27	II
70	**II**,**II/III**,**V**,VI=17.93; **II**=7.99; **II**,**II/III**,**V**=7.43; I,**II**=6.40; **II**,**II/III**=6.13; I, **II**,**II/III**=6.05	II,II/III,V
71	**II**,**III**=9.16; II/III=8.74; **II**=8.64; **III**=8.37; II/III,**III**=4.64; **II**,VII=3.68; **II**,II/III,**III**=3.39	II, III
72	**II**=14.93; II/III=11.25; III=10.58; **II**,II/III=9.21; **II**,III=8.50	II
73	**III**=21.42; **III,IV**=13.26; **III,IV**,VII=12.73; **III**,VI,VII= 11.40	III, IV
74	**II**=41.09; II/III=9.93	II
75	**II**=33.07; II/III=12.94; V=7.53	II
76	**II**,**V**=70.75	II, V
77	**II**=31.81; V=13.67; II/III=7.89	II
78	**II**=27.20; V=13.19; **II**,V=8.37; I,**II**=8.11	II
79	**V**=29.65; I,**V**=21.00	V
80	**II**=46.85; I,**II**=17.31	II
81	**II**=50.87	II
82	**II**=58.87	II
83	**II**=29.93; II/III=10.59; V=9.17; I,**II**=7.00	II
84	**II**=48.00; **II**;VI=7.18	II
85	**II**=43.48; II/III=11.66	II
86	**II**=31.37; II/III=15.66; **II**,II/III=6.71	II
87	**II**=35.15; II/III=17.37	II
88	**II**=25.21; II/III=18.04; **II**,II/III=7.26	II
89	**II**=21.92; II/III=18.45; **II**,II/III=5.76; **II**,V=3.08; V=2.80	II
90	**II,II/III,IV,V,VI,VII,VIII**=31.76; **II,II/III,IV,V,VI,VIII**=8.58; **II,II/III,V,VI,VII,VIII**=7.74; **II,II/III,IV,V,VI,VII**=7.41	II,II/III,IV,V,VI,VII,VIII
91	**II**=15.84; II/III=12.54; V=9.18; **II**,II/III=4.79; **II**,V=4.51; I,**II**=4.48	II
92	**II,II/III,III,IV,V,VI**=23.22; **II,III,IV,V,VI**=6.33; **II,II/III,III,IV,V**=6.12**; II,II/III,IV,V,VI**=6.02; I,**II**,**V**,VII,VIII=5.82; **II,II/III,III,IV,V,VI**,VII=4.85	II,II/III,III,IV,V,VI
93	**II**=48.13; II/III=15.25	II
94	**II**=15.36; II/III=11.57; **II**,**VII**=10.72; **VII**=8.38; II/III,**VII**=7.75	II, VII
95	**VII**=77.44	VII

96	**VII**=93.12	VII
97	**II**=49.87; II/III=16.56	II
98	**VI**=31.50; **II**=16.56; **II,VI**=14.38	VI, II
99	**VI**=29.39; **II**=19.17; **II**,**VI**=12.92	VI, II
100	**VI**=36.53, VII=8.62; IV=6.52	VI
101	**VI**=42.08; VII=11.21	VI
102	**VI**,**VII**=24.68; **VI**=20.25; **VII**=17.03	VI, VII
103	**VII**=76.53	VII
104	**II**=47.95; II/III=19.56	II
105	**II**=36.76; II/III=24.24	II
106	**II**=41.00; II/III=13.77	II
107	**II**=44.38; **II**,V=13.77	II
108	**II**=80.99	II
109	**II**=85.46	II
110	**II**=53.69	II
111	**I**,**II**=43.54; **II**=34.30	I,II
112	**II**=91.78	II
113	**II**=74.55	II
114	**II**=53.40	II
115	**II**=39.18; II/III=23.39	II
116	**II**=35.73; **II**,II/III=20.27	II
117	**II**=84.56	II
118	**II**=28.83; **II**,**V**=28.70	II, V
119	**II**=90.60	II
120	**II**=74.01	II
121	**II**=80.64	II
122	**II**=27.47; **V**=18.60; **II**,**V**=11.01	II, V
123	**V**=29.58; I,**V**=17.13; II=7.75	V
124	**II**=15.28; **V**=12.68; **II,V**=7.72; II/III,**V**=3.08; **II**,III,**V**=3.00; II/III=2.76; **II,**II/III,**V**=2.63; **II**,**V**,VIII=2.60; **II**,II/III=2.56	V, II
125	**II**,**III**,**V**=15.90; **II,III,V**,VIII=12.10; **II,V**=8.98; II/III,**V**=7.31; **II,III**=5.64; IV,**V**=4.79	V, II, III,
126	**II**=46.09; **II**, VI=15.77	II
127	**II**=63.89	II
128	**II**=48.65; I,**II**=8.73	II
129	**II**=41.42; II/III=14.45	II
130	**II**=69.89	II
131	**II**=69.24	II
132	**II**=84.04	II
133	**II**=84.67	II
134	**II**=73.58	II
135	**I**,**II**=56.86	I, II
136	**I**,**II**=31.64; **II**=31.29	I, II
137	**II**=65.75	II
138	**II**=55.59	II
139	**II**=30.66; I,**II**=19.55	II
140	**II**=43.85; I,**II**=24.50	II
141	**II**=40.27; I,**II**=11.05	II
142	**II**=70.08	II
143	**II**=64.63	II
144	**II**=47.17; I,**II**=13.22	II
145	**II**=44.67; I,**II**=18.76	II
146	**II**=59.12	II
147	**I**,**II**,**V**=62.59	I, II, V
148	**II**=80.64	II

149	**II**=66.13	II
150	**II**=17.93; **II/III**=15.58; **II, II/III**=8.66; **II,II/III**,IV=3.25; II,**II/III**,III=2.73; II,**II/III**,VII=2.59	II, II/III
151	**II**=59.59	II
152	**II**=50.75	II
153	**II**=77.84	II
154	**II**=81.98	II
155	**II**=75.97	II
156	**II**=82.00	II
157	**II**=73.55	II
158	**II**=79.54	II
159	**II**=55.31	II
160	**II**=70.58	II
161	**II**=47.75; **II**,VIII=10.35	II
162	**II**=28.52; **II, II/III**=20.21; **II/III**=17.07	II, II/III
163	**II/III**=45.30; II,**II/III**=17.72	II/III
164	**VI**=30.61; **II**=17.18; **II,VI**=14.90	VI, II
165	**VI**=45.20; V=9.24	VI
166	**VI**=42.22; VIII=12.76;	VI
167	**V**=56.58	V
168	**V**=66.07	V
169	**V**=61.92	V
170	**VI**=38.25; **VIII**=25.02	VI, VIII
171	**VI**=44.47; **VI**,VII=17.32	VI
172	**VII,VIII**=30.29; **VIII**=30.23	VIII, VII
173	**VII**=56.41	VII
174	**VI**=52.19	VI
175	**VI**=41.77; VIII=14.01	VI
176	**II**=12.20; **II,V**=4.26; I,**II**=4.11; **II**,VI=3.87; **II**,II/III,**V**,VI=3.54; **II**,**V**,VI=3.45; **II**,II/III,**V**=2.32; **V**=2.29; **II**,II/III=2.17; I,**II,V**=2.05; **II**,IV,**V**=1.87; **II**,IV,**V**,VI=1.86; **II**,II/III,IV,**V**,VI=1.80; **II**,**V**,VI,VII=1.72; **II**,II/III,IV,**V**,VI,VII=1.65; I,**II**,II/III,**V**,VI=1.54	II, V
177	**VIII**=39.48; **VI**=26.52	VIII, VI
178	**VI**=51.38	VI
179	**VIII**=61.16	VIII
180	**VIII**=81.48	VIII
181	**VIII**=85.42	VIII
182	**VIII**=87.78	VIII
183	**VIII**=60.88	VIII
184	**VI**,**VII**=15.10; **VII,VIII**=14.71; **VI**=13.75; **VI**,**VII**,**VIII**=12.76	VI, VII, VII
185	**VIII**=54.04	VIII
186	**VIII**=91.62	VIII
187	**VIII**=97.98	VIII
188	**VIII**=61.75	VIII
189	**VII**=88.66	VII
190	**VIII**=41.92; VI=17.70	VIII
191	**VI,VIII**=45.64; **VI**=40.97	VI, VIII
192	**VI,VII,VIII**=41.49; **VI**,**VII**=20.28	VI, VII,VIII
193	**VI,VII,VIII**=50.83	VI, VII,VIII
194	**VIII**=69.27	VIII
195	**VIII, IX**=25.18; **IX**=24.16; **VIII**=23.84	VIII, IX
196	**VI,VIII,IX**=54.65	VI,VIII,IX
197	**VI**=51.98	VI
198	**VI**=28.02; V=11.65; II=9.23; II, **VI**=7.69	VI
199	**VI**=51.94	VI

200	**VII**=26.77; **VI**=20.24; **VI**,**VII**=15.03	VII, VI
201	**VII**=34.52; **VI**=32.69	VII, VI
202	**VI**=35.98; V=14.22	VI
203	**V**=30.67; **VI**=25.68	V, VI
204	**V**=43.06;VI=22.36	V
205	**V**=69.37	V
206	**II,V**=50.48	II, V
207	**VI**=33.49; II=18.17	VI
208	**V**,**VI**=19.03; II,**V**,**VI**=17.45; **VI**=15.53	VI, V
209	**VI**=14.00; **V**,**VI**=11.94; II,**V**,**VI**,VII=10.42; II,**V**,**VI**=9.26; **V**=7.31	VI, V
210	**VI**=34.26; **II**=31.45	VI, II
211	**II**=41.65; VI=22.10	II
212	**VII**=43.33; VI,VIII=7.97	VII
213	**VII**=33.38; **VII**,VIII=13.27; V,VI,**VII**,VIII=9.65	VII
214	**VI**,**VII**=92.12	VI,VII
215	**II**=54.89	II
216	**II**=64.34	II
217	**II**=65.88	II
218	**II**=69.52	II
219	**II**=85.82	II
220	**I**,**II**=46.97; **II**=42.45	I, II
221	**II**=99.74	II
222	**II**=50.95	II
223	**II**=68.89	II
224	**II**=81.53	II

Appendix 4.8.4. Table S4. Biomes definition for each node in Falconiformes based in probability values for each node. (I= Tropical rain forest; II= Tropical deciduous woodland; II/III= Savanna; III= Subtropical Desert ; IV= Sclerophyllous woodland-shrubland; V=Temperate evergreen forest; VI=Temperate broadleaf deciduous forest; VII= Steppe to cold desert; VIII=Boreal coniferous forest (Taiga);IX=Tundra).

Node	Probability of combinations until (50%)	Defined biomes
1	**II/III**=5.11**; I,II/III**=5.03; **II,II/III**=4.79; **I,II,II/III**=4.66; **I,II/III**,V=4.08; **II/III**,V=4.02; **I,II,II/III**,V=3.96; **I,II**=3.95; **II,II/III,**V=3.39; **II**=3.75; **I,II**,V=3.37	I,II,II/III
2	**II/III**=9.65; **I,II,II/III**,V,VI=8.57; **I,II,II/III**,V=7.13; **I,II**,**II/III**=5.62; **II**=5.30; **II,II/III**=5.11**; I,II/III**=4.60; **I,II/III**,V=4.38	I,II,II/III
3	**I,II,II/III,V**,VI= **I,II,II/III,V**= **II/III**= **I,II,II/III**= **II,II/III,V,VI**= **I,II/III,V**= **I,II,II/III,V,VIII**= **I,II/III**=	I, II, II/III, V
4	**I,II,II/III**,V=10.16; **I,II,II/III**=9.74; **I,II,II/III**,V,VI=7.40; **II**=6.56; **II/III**=6.53; **I,II**=6.43; **I,II/III**=6.10	I, II, II/III
5	**I,II**=15.09**; I,II/III**=13.10; **I,II,II/III**=11.22; **I,II/III,V**=10.24; **I,II,V**=7.28	I, II, II/III
6	**I,II**=16.54; **II**=16.28; **I,II**,II/III=8.58; **I,II**,V=6.44; **I,II**,II/III,V=6.24	I, II
7	**I,II**=28.26; **I,II**,II/III=12.76; **I,II**,V=8.83; **I,II**,II/III,V=7.75	I, II
8	**II**=30.50; **I,II**=25.09	I, II
9	**II**=26.01; I,**II**=18.20; I,**II**,II/III=6.48	II
10	**II/III**=12.14; **I,II,II/III**,V,VI=7.67; **I,II,II/III**,V=6.41; **II**=5.69; **I,II,II/III**=5.45; **II,II/III**=5.39; **I,II/III**=4.96; **I,II/III**,V=4.41	I, II, II/III
11	**I,II,II/III,V**,VI=17.83; **I,II,II/III,V**=10.03; **II,II/III,V**,VI=6.87; **I,II,II/III,V**,VIII=5.77; **I,II,II/III**=5.41; **II/III**=3.90; **I,II/III,V**=3.81	I, II, II/III, V
12	**I,II,II/III,III,IV,V,VI,VII,VIII**=34.32; **I,II,II/III,IV,V,VI,VII,VIII**=8.96; **I,II,II/III,III,IV,V,VI,VII**=8.48	I,II,II/III,III,IV,V,VI,VII,VIII
13	**II/III**=18.89; **II**=14.69; **II,II/III**=7.21; I,**II/III**=6.74; I,**II,II/III**=5.78	II, II/III
14	**II**=6.53; I,**II**=4.05; **II/III**=3.55; I,**II/III**=3.33; **II**,VI=2.64; I,**II,II/III**,VII=2.51; I,**II,II/III**=2.32; I,**II/III**,V=2.24; **II,II/III**=1.73; **II**,VII=1.68; I,**II,II/III**,V=1.56; V=1.53; **II,II/III**,IV,V,VI,VII=1.48; **II,II/III**,VII=1.47; VI=1.36; **II**,V,VI=1.26; I,**II,II/III**,V,VI=1.26; **II**,IV,VI=1.21; **II**,IV,VI,VII=1.21; **II,II/III**,III,IV,V,VI,VII=1.20; **II,II/III**,III,IV,V,VI=1.17; **II/III**,V=1.16; I,**II**,V=1.15; **II/III**,VII=1.14; I,**II,II/III**,V,VII=1.14; **II**,IV,V,VI=1.05	II, II/III
15	**I,II**=18.76; **II**=14.95; **I,II**,II/III=10.05; **I,II**,II/III,V=9.87	I, II
16	VII=10.88; VI=9.80; IV=4.90; II/III=4.43; VI,VII=2.92; IV,VII=2.77; IV,VI=2.52; III=2.49; II/III,VII=2.44; V=2.10; VIII=1.76; V,VI=1.64; IV,VI,VII=1.62	Indet.
17	**VII,IX**=16.66; **VI,VII,VIII,IX**=14.47; **VI,VII,IX**=13.50; **VII,VIII,IX**=11.52	VI, VII, VIII, IX
18	**VI,VII,**VIII,**IX**=22.24; **VII**=14.52; **VI,VII,IX**=13.38	VI, VII, IX
19	**VI,VII,VIII,IX**=49.34; **VI,VIII,IX**=11.56	VI, VII, VIII, IX

20	**II/III**=12.15; **I**,**II**,**II/III**,V,VI=8.46; **I,II,II/III**,V=7.76; **I**,**II**,**II/III**=7.20; **II**,**II/III**=6.50; **II**=6.04; **I**,**II/III**=5.85	I,II,II/III
21	**II/III**=18.96; II,**II/III**=8.17; II=8.11 **I,II,II/III**=7.56; I,**II/III**=7.28	II/III
22	**I**,**II**=24.89; **II**=11.79; **I**,**II**,II/III=9.12; **I**,**II**,V=8.87	I, II
23	**I**,**II**=28.42; **II**=15.24; **I**,**II**,V=11.30	I, II
24	**I,II**=40.78; **II**=18.75	I, II
25	**II**=20.00; **II**,V=16.32; I,**II**=15.60	II
26	**II/III**=14.68; **II**=9.87; **II**;**II/III**=6.65; I,**II**,**II/III**=6.25; I,**II/III**=5.82; I,**II**,**II/III**,V=5.56; I,**II**,**II/III**,V,VI=5.54	II, II/III
27	**I**,**II**,**II/III**,V,VI=11.48; **II/III**=11.14; **I**,**II**,**II/III**,V=7,48; **I**,**II**,**II/III**=7.36; **II**,**II/III**=7.14; **II**=6.30	I,II,II/III
28	**II/III**=15.18; **II**=13.42; I,**II**,**II/III**, V,VI=7.87; V=6.35; VI=5.94; **II**,**II/III**=4.85	II,II/III
29	II=21.41; II/III=17.30; VI=12.44	Indet.
30	**VI**=29.94; II=21.10	VI
31	**II**=26.55; **VI**=25.74	II, VI
32	**VI**,**VII**,**VIII**,**IX**=45.81; **VI**,**VIII**,**IX**=9.49	VI, VII, VIII, IX
33	**II**=66.17	II
34	**VI**,**VII**,**VIII**=35.46; VI,VIII=12.28; **VI**,**VII**=11.28	VI, VII, VIII
35	**II/III**=18.12; II=16.76; V=10.41; II,**II/III**=4.16; **II/III**,V=3.32	II/III
36	II/III=17.02; II=15.99; V=10.20; IV=4.03; II,II/III=3.49	Indet.
37	II=10.25; **II/III**=8.92; V=6.89; I,**II/III**=4.48; I,II=4.28; II,**II/III**=4.19; **II/III**,V=4.04; II,V=3.90; I,**II/III**,V=2.69; I,II,**II/III**=2.28	II/III
38	**I**,**II/III**,V=13.09; **I,II/III**=9.55; **I,II,II/III**,V=8.71; **II/III**,V=7.36; **I,II,II/III**=6.88; **I,II**=6.25	I,II,II/III
39	**II**=8.34; **II**,V=3.24; **II**,IV,V=2.84; **II**,II/III=2.78; **II**,IV,V,VI=2.76; I,**II**=2.70; IV=2.65; **II**,II/III,IV,V=2.38; II/III=2.38; **II**,II/III,III,IV=2.34; V=2.28; **II**,II/III,IV=2.13; **II**,II/III,III=2.13; **II**,VI=2.05; **II**,II/III,III,IV,V=2.03; **II**,III=2.00; IV,V=1.89; II/III,IV=1.83; II/III,IV,V=1.80	II
40	**II**=32.69; IV=13.14; I,II=8.55	II
41	**IV**=29.46; III=14.25; II=8.92	IV
42	**III**=27.41; II=9.67; IV=7.03; VI=5.13; II,**III**,IV,V,VI,VII,VIII=3.41	III
43	**II**,**IV**,**V**,**VI,VII,VIII**=14.54; **II**,**V**,**VI**,**VII**,**VIII**=6.78; **IV,V,VI,VII,VIII**=6.71; **II,IV,V**,**VII,VIII**=4.48; **II,V**,**VII**,**VIII**=4.40; **II**,**V,VI,VIII**=4.34; **IV**,**V**,**VI,VIII**=3.83; **II**,**V**=3.73; **II**,**V**,**VI**=3.64	II, IV, V, VI, VII, VIII
44	II/III=14.09; II=11.47; V=7.43; IV=5.87; III=5.87; VI=4.29 II,II/III=3.10	Indet.
45	II/III=12.45; III=10.87; II=9.10; II/III,III=4.67; IV=4.00; II,II/III=3.59; II,III=3.11; III,IV=2.67	Indet.
46	**III**=4.72; **III,IV**=3.13; **II/III,III**=3.12; **II/III,III,IV**=2.63; **II/III**,**III**,**IV**,VII=2.44; II,**II/III**,**III**,**IV**,VII=2.35; I,II,**II/III**,**III**,**IV**,V,VI,VII=2.26; II,**II/III**,**III**,**IV**=2.19; I,II,**II/III**,**III**,**IV**,V,VI=2.14; II,**II/III**,**III**,**IV**,V,VI,VII=1.91; II,**II/III**,**III**,**IV**,V,VII=1.84; II,**II/III,III,IV**,V=1.75; **II/III,III,IV**,VI,VII=1.73; I,II,**II/III**,**III**,**IV**,V=1.73; **II/III**=1.68; II,**II/III**,**III**,**IV**,VI,VII=1.58; **II/III**,**III**,VII=1.55; **III**,**IV**,VII=1.50; I,II,**II/III**,**III**,**IV**,V,VI,VII,VIII=1.49; **II/III**,**III**,**IV**,VI=1.48; II,**II/III**,**III**,**IV**,V,VI=1.44; II,**II/III**,**III**=1.40; **IV**=1.38;	II/III, III, IV

	I,II,**II/III**,**III**,**IV**=1.25; **III**,**IV**,VI=1.24	
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49	**I,II,II/III,III,IV,V,VI,VII,VIII,IX**=25.45; **I,II,II/III,III,IV,V,VI,VII,VIII**=12.96; **I,II,II/III,III,IV,V,VI,VII,IX**=6.88; **I,II,II/III,III,IV,V,VI,VII**=6.39	I,II,II/III,III,IV,V,VI,VII,VIII,IX
50	**I,II,II/III,III,IV,V,VI,VII,VIII,IX**=65.33	I,II,II/III,III,IV,V,VI,VII,VIII,IX
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62	**I,II/III**=28.29; **I,**II,**II/III**=24.34	I, II/III
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5 Conclusiones

5 Conclusiones

En esta tesis se han analizado los patrones macroevolutivos de las aves no paseriformes y la influencia de los diversos cambios ambientales en sus procesos de radiación, dispersión y adaptación a lo largo de los últimos 90 millones de años, con especial énfasis en el Cenozoico. Esto ha sido posible gracias a la gran cantidad de información ecológica y biogeográfica existente en la literatura. Sin embargo, también es cierto que paradójicamente este gran conocimiento biológico de las aves actuales contrasta con el apenas emergente, pero también creciente, conocimiento filogenético y paleontológico de los diversos grupos. Considerando esto, en este proyecto se emprendió la labor de integrar toda la información disponible para reconstruir una aproximación histórica a gran escala sobre cómo han evolucionado las aves modernas, y así conocer los posibles agentes promotores de diversos procesos que configuran la dinámica macroevolutiva de un grupo tan diverso, que muchas veces quedan enmascarados en otro tipo de trabajos a menor escala espacial o temporal.

Teniendo en cuenta que esta tesis doctoral abarca la macroevolución de las aves no paseriformes desde diferentes perspectivas espacio-temporales y escalas taxonómicas, considero pertinente exponer los principales hallazgos y aportaciones de cada capítulo independientemente.

Capítulo 2. *Especialización ecológica y cambios climáticos globales como reguladores de los patrones evolutivos en aves no paseriformes.*

La hipótesis del uso de los recursos, propuesta por E.S.Vrba, sugiere una conexión directa entre los cambios físicos que ha sufrido la tierra y los patrones de diversidad. De esta manera, los procesos de extinción y especiación de los grupos naturales están relacionados y son potenciados en diferentes momentos por cambios climáticos y procesos tectónicos. Mientras que hasta este momento esta hipótesis solo había sido

contrastada con datos de mamíferos, Nuestros resultados, sugieren también una relación próxima entre estos procesos y los patrones macroevolutivos de aves no paseriformes. De acuerdo con lo establecido en la hipótesis, se ha encontrado una alta frecuencia de especies restringidas a la ocupación de un solo bioma (especialistas). Estas especies estarían principalmente asociadas a los biomas situados en los extremos climáticos (pluvisilva, desierto, estepa y tundra), los cuales históricamente han presentado diversos procesos de expansión, contracción y fragmentación en sus áreas de distribución debido a cambios climáticos. Los patrones predominantes de especialización ecológica asociada a biomas particulares fueron conservados independientemente del comportamiento migratorio de las especies. Sin embargo, es de anotar que las especies migratorias presentaron una ocupación biómica relativamente más amplia con respecto a las sedentarias. Asimismo, los resultados sugieren que la evolución de estrategias migratorias habría facilitado la diversificación y especialización de algunos linajes en biomas hostiles y con estacionalidad de recursos como sucede con muchas especies de estepa y tundra. Por otra parte, cuando fueron consideradas las diferencias tróficas, los especialistas de bioma son más abundantes entre los taxones herbívoros con respecto a omnívoros y faunívoros respectivamente. Finalmente, algunas excepciones al marco explicativo de la hipótesis parecen estar asociados con la biogeografía de los ambientes de montaña y a la heterogeneidad de hábitat asociada a la dinámica ecotonal entre la pluvisilva y el bosque seco tropical. El análisis y amplia consistencia de esta hipótesis, evaluada por primera vez para las aves en esta tesis doctoral, se suma a los hallazgos de otros trabajos con mamíferos en el respaldo de una hipótesis evolutiva que hasta el momento muestra un alto nivel explicativo.

Capítulo 3. *"Out of South America": añadiendo fósiles y tectónica para una nueva historia biogeográfica de las aves modernas (Neornithes).*

Se han realizado diversos análisis de reconstrucción paleobiogeográfica a partir de una propuesta filogenética que incluye todas las familias actuales de aves no paseriformes y sus parientes extintos mejor conocidos, así como una amplia base de datos biogeográficos y mapas consolidada para 30 intervalos temporales, abarcando cerca de 90 millones de años. Se establecieron diversos modelos que permitieron conocer la relación e influencia entre diversos procesos históricos que han acaecido desde finales del Cretácico con diferentes episodios de dispersión, diversificación y extinción evidenciados en distintos linajes de aves durante diversos periodos de su historia

evolutiva. Los resultados obtenidos apuntan hacia la consolidación de Gondwana y específicamente Sudamérica, como centro de origen y diversificación de las aves modernas. Asimismo, nuestros resultados sugieren un relevante papel de África y Europa en la dispersión y posterior colonización de los linajes hacía los continentes del Hemisferio Norte. Esta ruta permitiría que muchos linajes desarrollaran una distribución geográfica muy amplia en un momento temprano de su historia evolutiva.

El modelo más robusto estadísticamente sugiere un papel muy relevante de la dispersión en los procesos de colonización y diversificación de muchos grupos. Igualmente, nuestro modelo macroevolutivo establece diversos momentos de aumento en las tasas de colonización, muchos de ellos relacionados estrechamente con importantes procesos globales a nivel biótico y abiótico. Tres importantes oleadas de dispersión son detectadas a lo largo de la historia evolutiva de las aves, la primera tendría lugar durante el Cretácico Superior por parte de linajes de Neornithes asociados con ambientes acuáticos y semiacuáticos, así como algunos cursoriales. Esta primera oleada sufriría un importante descenso hacía finales del Cretácico, en relación con la profunda crisis ambiental que causó la extinción de un amplio componente de la biota terrestre. La segunda estaría relacionada con las condiciones de calentamiento global durante el Paleoceno y el Eoceno que llevarían a la expansión de los ambientes tropicales hacia altas latitudes, ofreciendo un amplio abanico de nuevos nichos para la diversificación; esta sería más destacada en linajes arborícolas. La tercera fase de dispersión sucedería desde el Oligoceno superior hasta el Mioceno inferior y estaría protagonizada especialmente por linajes de aves marinas y playeras, así como de aves cursoriales y arborícolas adaptadas a los ambientes abiertos. Este proceso habría estado relacionado con la aparición de nuevas corrientes marinas relacionadas con el desplazamiento de masas continentales y asociadas al enfriamiento global y el desarrollo del casquete antártico durante el Neógeno, y en los ambientes continentales al desarrollo y posterior expansión de los biomas abiertos gracias a la evolución de plantas C4. Pese a que durante el Mioceno se estabilizarían muchos de los procesos de colonización, después del Mioceno Medio, con la consolidación de los regímenes climáticos estacionales en latitudes septentrionales muchos linajes adaptados exclusivamente a condiciones climáticas tropicales desaparecerían de Eurasia y Norteamérica y retraerían sus áreas de distribución hacía latitudes más ecuatoriales. Lo anterior habría configurado la amplia distribución tropical de muchos linajes de aves observada actualmente.

Capítulo 4. *Una perspectiva filogenética sobre la ocupación y adaptación de las aves a diferentes biomas: Galliformes y Falconiformes como casos de contraste.*

Como se evidenció anteriormente, la dinámica histórica de los biomas se constituye como fundamental para comprender los procesos macroecológicos y macroevolutivos. En este capítulo se abordó una evaluación más profunda de la ocupación de los diferentes biomas, esta vez teniendo en cuenta la historia evolutiva de las especies de dos grupos de aves desde una perspectiva filogenética: Galliformes y Falconiformes. Esto nos permitió conocer qué factores ambientales y adaptativos pueden condicionar la ocupación y colonización de ciertos biomas. Asimismo, este aspecto nos llevó a analizar el concepto de ocupación biómica bajo la hipótesis de la conservación de nicho. Lo cual sería fundamental para comprender las diferencias en la diversidad que observamos en los diversos biomas, así como su relación con diversos aspectos específicos de la historia natural de los dos linajes. Los resultados obtenidos para ambos grupos son ampliamente coherentes con la conservación filogenética del nicho. Se observó una alta tendencia hacia conservar el bioma de ocupación ancestral en la amplia mayoría de los biomas; si bien los biomas extremos (excepto el desierto), como la pluviisilva, la estepa y la tundra presentarían los valores más altos de conservación, constituyendo como un importante respaldo filogenético a las hipótesis evolutivas discutidas en el capítulo 2. Desde una perspectiva histórica, nuestro análisis permitió establecer cómo diversos procesos climáticos de enfriamiento global y geológicos durante el Mioceno serían fundamentales en la adaptación y evolución de los nichos climáticos en diversos linajes dentro de los dos grupos estudiados. Es de destacar que pese a una ancestría claramente ligada a los ambientes tropicales, la evolución y predominancia que alcanzarían durante el Mioceno los biomas estacionales cálidos abiertos y semiabiertos, representados por los bosques secos tropicales y las sabanas, mostraría ser determinante en los procesos de diversificación de ambos grupos, y probablemente algunas de las adaptaciones fisiológicas desarrolladas en relación a estos ambientes habrían sido claves en la posterior colonización de otros biomas tanto tropicales como templados.

Finalmente, a través de los análisis realizados en los diferentes capítulos de esta tesis, se ha logrado profundizar en diversas cuestiones macroevolutivas de las aves mediante la potente integración de información filogenética, biogeográfica y paleontológica en un estudio que logra arrojar mayor luz sobre la evolución de las aves y sus patrones históricos de diversificación.

5.1 Reflexión final y perspectivas de futuro

A lo largo del desarrollo de esta Tesis Doctoral se ha evidenciado la gran necesidad e importancia de la integración de las diversas fuentes de información en un enfoque hacia la generación y contraste de hipótesis evolutivas más amplias y con mayor poder explicativo. Esto es fundamental para comprender la dinámica de la biota en su conjunto así como determinados patrones que no se evidencian en estudios a pequeña escala. Este trabajo consolida un escenario macroevolutivo para la evolución de las aves de alto valor explicativo, y que integra toda la información biótica y abiótica tanto del presente como del pasado. En este sentido nuestra aproximación en el estudio de la macroevolución de las aves propone un horizonte explicativo que pone de manifiesto la destacada similitud de la dinámica macroevolutiva de las aves con la ampliamente estudiada en los mamíferos, pese a que estos últimos poseen un registro fósil más rico y las aves son consideradas muchas veces más "independientes" ecológicamente hablando, debido a la capacidad voladora de la mayoría de sus especies. Lo anterior es destacable porque marca un importante precedente del papel que desempeñan los procesos históricos globales en la evolución de las biotas.

Aunque éste trabajo se constituye como un importante precedente, es un trabajo que como todo en ciencia, deberá ser revalidado. Nuevos y diversos datos continuarán saliendo a la luz; descubrimiento de nuevos fósiles, obtención de propuestas filogenéticas más amplias y más robustas, nuevas especies. El hecho de que la ciencia avance se constituye en una renovación constante. Con ello, nuestras hipótesis y nuestros planteamientos podrán ser respaldados o rechazados (espero que lo primero). Sin embargo, eso es lo bonito que tiene la ciencia, es dinámica y activa. En el caso particular de la paleontología y la biología evolutiva, donde trabajamos armando el *puzzle* del pasado, siempre tendremos nuevas preguntas e interrogantes por el sencillo hecho de que *nadie estuvo allí*; nuestros planteamientos son meras aproximaciones para tratar de reconstruir una historia natural. Es por eso nuestro deber que estas aproximaciones sean cada vez más rigurosas y precisas a la luz de los nuevos hallazgos. En este sentido, y sin temor a equivocarme, el crecimiento exponencial del estudio y desarrollo de nuevas técnicas filogenéticas esta llamado a aportar una información muy valiosa sobre las relaciones entre las especies a la vez que será la base para nuevos análisis macroevolutivos. Sin embargo, es importante fomentar una constante y creciente relación entre las filogenias y los fósiles, muchas veces estudiados

independientemente. Parafraseando a Einstein: "*las filogenias sin los fósiles están ciegas y los fósiles sin las filogenias están cojos*".

Conocer los patrones históricos de cómo han respondido las avifaunas ante los diferentes cambios ambientales que sucedieron en el pasado es fundamental para evaluar hipótesis en biología de la conservación, dado el contexto del actual cambio climático. El gran conocimiento de las avifaunas como importantes componentes de la biodiversidad actual puede ser complementado por el procedente del estudio los procesos del pasado, de esta manera se pueden generar predicciones más precisas sobre la respuesta ecológica de especies y comunidades. Asimismo, este trabajo logra evidenciar que las aves pueden ser tan dependientes y susceptibles frente a los cambios ambientales como otros grupos animales. Siendo estos cambios y variaciones, los principales agentes configuradores de sus patrones de diversidad.

Desde el momento en que esta tesis fue planteada fui plenamente consciente del gran reto que suponía integrar una cantidad ingente de información para ver los patrones de la evolución a gran escala. Confieso que habría querido realizar muchas más cosas que se quedan en el tintero a la espera de nuevos hallazgos fósiles y de filogenias más completas. Personalmente espero que en un futuro no muy lejano pueda contribuir en ambos campos. Durante el desarrollo de esta tesis doctoral descubrí que en realidad el registro fósil de las aves puede aportar una información fundamental, la cual es *real* y directa, nos da idea de una ocupación biómica y geográfica ancestral. Es cierto que existe una importante diferencia en el conocimiento de las aves del pasado en diversas regiones del mundo, sin embargo ese no debe ser un impedimento para emplear la valiosa información que nos aportan. Nuestras inferencias pueden ser un importante punto de partida para la búsqueda de nuevos fósiles, los cuales ayudaran a su vez en hacer más sólidas y precisas nuestras aproximaciones.

Las aves, esos dinosaurios actuales tan apasionantes, aún guardan las repuestas a muchas preguntas que hoy siguen abiertas. Cómo evolucionan las diversas estrategias dietarias, reproductivas y comportamentales, o cuáles son los procesos que llevan a la amplia diversidad morfológica de sus picos, son sólo algunas de ellas. Sin embargo hay muchas incógnitas que sólo pueden ser respondidas a la luz de nuevos fósiles, y afortunadamente el registro de las aves está creciendo significativamente. La paleornitología es un campo emergente que aspira no sólo a la simple descripción clásica de los nuevos hallazgos. Cada vez son más abundantes los trabajos donde se aplican a los fósiles novedosas metodologías de análisis y nuevas inferencias paleoecológicas comienzan a emerger a partir del estudio de las avifaunas del pasado.

En general, cada vez más la paleontología y la biología evolutiva generan explicaciones en un contexto integrador, comienzan a abrir nuevas líneas de investigación hacia el estudio de la evolución desde una perspectiva más integral y holística. Me alegraría formar parte de esta tendencia…